Transportation
Library
TA
1
.A526

TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS

(INSTITUTED 1852)

TRANSPORTATION LIBRARY
UNIVERSITY OF MICHIGAN

VOL. LXII

MARCH, 1909

Edited by the Secretary, under the direction of the Committee on Publications.
Reprints from this publication, which is copyrighted, may be made on condition that the full title of Paper, name of Author, and page reference are given.

NEW YORK

PUBLISHED BY THE SOCIETY

1909

Entered according to Act of Congress, in the year 1909, by the AMERICAN SOCIETY OF CIVIL ENGINEERS, in the Office of the Librarian of Congress, at Washington.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CONTENTS

PAPERS

No.		PAGE
1092	**IRRIGATION: AN INFORMAL DISCUSSION.**	
	By GEORGE G. ANDERSON	1
	F. H. NEWELL	10
	J. P. A. MAIGNEN	15
	A. L. FELLOWS	19
	W. W. FOLLETT	22
	GARDNER S. WILLIAMS	37
	F. C. FINKLE	37
	THOMAS H. MEANS	42
	G. N. HOUSTON	45
	RICHARD R. LYMAN	46
	ARTHUR P. DAVIS	52
	GEORGE G. ANDERSON	53
1093	**CURVE RESISTANCE IN WATER PIPES.**	
	By **Ernest W. Schoder**	67
	Discussion:	
	By GEORGE JACOB DAVIS, JR	97
	ERNEST W. SCHODER	112
1094	**THE SINKING OF THE PIERS FOR THE GRAND TRUNK PACIFIC BRIDGE AT FORT WILLIAM, ONTARIO, CANADA.**	
	By **H. L. Wiley**	113
	Discussion:	
	By C. R. FICKES	120
	GEORGE B. FRANCIS AND ROBERT A. MARSHALL	123
	F. W. SKINNER	129
	H. L. WILEY	132
1095	**NOTES UPON DOCKS AND HARBORS.**	
	By **Luther Wagoner**	135
	Discussion:	
	By W. B. RUGGLES	149
	E. P. GOODRICH	152
	HOWARD J. COLE	153
	RUDOLPH HERING	155
1096	**CATENARY TROLLEY CONSTRUCTION.**	
	By **Oliver S. Lyford, Jr.**	157
	Discussion:	
	By JOSEPH MAYER	175
	CHARLES RUFUS HARTE	180
	W. K. ARCHBOLD	185
	THEODORE VARNEY	187
	GEORGE N. COLE	190
	W. S. MURRAY	191
	R. D. COOMBS	194
	OLIVER S. LYFORD, JR.	196

No.		PAGE
1097	**THE HYDRO-ELECTRIC DEVELOPMENT AND TRANSMISSION LINES OF THE CANADIAN NIAGARA POWER COMPANY.**	
	By **A. H. Van Cleve**	199
	Discussion:	
	By JOHN C. PARKER	238
	WILLIAM J. BOUCHER	241
	A. H. VAN CLEVE	241
1098	**FORESTS AND RESERVOIRS IN THEIR RELATION TO STREAM FLOW, WITH PARTICULAR REFERENCE TO NAVIGABLE RIVERS.**	
	By **H. M. Chittenden**	245
	Discussion:	
	F. COLLINGWOOD	319
	THOMAS P. ROBERTS	321
	STEPHEN CHILD	328
	L. J. LE CONTE	329
	F. B. MALTBY	332
	J. FRANCIS LE BARON	333
	EDWARD P. NORTH	336
	A. MILLER TODD	340
	WILLIAM W. HARTS	347
	GEORGE OTIS SMITH	361
	GEORGE F. SWAIN	365
	W. H. LEFFINGWELL and A. M. STRONG	377
	BAILEY WILLIS	384
	M. O. LEIGHTON	394
	W. D. PICKETT	423
	ROBERT E. MCMATH	430
	H. F. LABELLE	437
	EMIL KUICHLING	445
	ROBERT FLETCHER	447
	J. P. SNOW	450
	CLARENCE T. JOHNSTON	454
	GIFFORD PINCHOT	456
	H. M. CHITTENDEN	466

MEMOIRS OF DECEASED MEMBERS

THOMAS FITCH ROWLAND, HON. M. AM. SOC. C. E.	547
RICHARD MILFORD BERRIAN, M. AM. SOC. C. E.	550
STEPHEN ARNOLD MITCHELL, M. AM. SOC. C. E.	552
GEORGE W. RAFTER, M. AM. SOC. C. E.	554
CHARLES HAROLD TUTTON, M. AM. SOC. C. E.	560
CLARENCE GEORGE VAUGHN, M. AM. SOC. C. E.	562
JAMES ISAAC HAYCROFT, ASSOC. M. AM. SOC. C. E.	564

PLATES

PLATE		PAPER	PAGE
I.	Reinforcement and Paving, Terry Lake Embankments; and Sluiceway and Drop Below Gates, Windsor Reservoir	1092	47
II.	Concrete Spillway, Deseret Irrigation Co. and Irrigated Lands Co., Millard County, Utah	1092	51
III.	Experimental Pipe Line at Cornell University Hydraulic Laboratory; Nozzle and Curves	1093	69
IV.	Diagram Showing Results of Experiments on Curve Resistance in Water Pipes	1093	79
V.	Interiors of Cast-Iron "Drainage" Elbow No. 3, and Cast-Iron "Short Turn" Elbow, No. 4	1093	111
VI.	Views of Grand Trunk Pacific R. R. Bridge, Fort William, Ont.	1094	115
VII.	Pivot Pier and Derrick; and Falsework and Derrick Car, Pivot Pier	1094	117
VIII.	Interior of Shell of Pivot Pier, Showing Bracing; and Completed Piers	1094	119
IX.	Statistical Chart Showing the Progress of Banking, Commerce, Shipping, Population, etc.	1095	139
X.	Derrick Car for Setting Trolley Poles, D. & I. R. R.	1096	159
XI.	Erecting Brackets, and Stringing Wires	1096	163
XII.	Straining and Gauging Trolley Wire, etc.	1096	167
XIII.	Insulator Pull-Off and Anchorage	1096	169
XIV.	Line Insulator, Steady Strain, and Deflector	1096	173
XV.	Views: Relation Between Signals and Poles; Light Tower; and Bracket Hoist	1096	179
XVI.	Views Showing Siemens-Halske Compound Catenary; and Compound Double Catenary	1096	181
XVII.	Angle-Iron Bridge, Syracuse, Lake Shore & Northern R. R.; and Smoke Coatings on Insulators	1096	183
XVIII.	Views of Siemens-Halske Light Steel Bridges	1096	185
XIX.	Standard Wooden-Pole Construction on Double-Track Road; and Catenary Bridge Construction	1096	187
XX.	Views of Coffer-Dam, Canadian Niagara Power Plant	1097	201
XXI.	Views of Ice Rack, and Submerged Arches under Forebay Wall	1097	203
XXII.	Views of Wheel-Pit, and Tunnel Portal	1097	205
XXIII.	General Plan of the Works of the Canadian Niagara Power Company	1097	207
XXIV.	Views of Power-House	1097	209
XXV.	Views of Part of Penstock, and Power-House Interior	1097	211
XXVI.	Sections of Power-House and Wheel-Pit	1097	213
XXVII.	General Arrangement of Tail-Water Regulating Gate	1097	215
XXVIII.	Cross-Section of 10 000-H. P. Turbine	1097	217
XXIX.	General Arrangement of 10 000-H. P. Turbine	1097	219
XXX.	Oil Step Bearing	1097	221
XXXI.	Oil-Pressure Governor, and Switch-Board	1097	223
XXXII.	Views of Draft-Tubes, and Transmission Line	1097	225
XXXIII.	General Map of Transmission Lines, Niagara Falls to Buffalo	1097	227
XXXIV.	Plan and Details of Standard Pole for Transmission Line	1097	233
XXXV.	Section and Elevation of Bertie Hill Tower, Fort Erie, Ont.	1097	235
XXXVI.	High Tower on Transmission Line	1097	237
XXXVII.	Views of Snow in Forest, and Snow-Drift in Yellowstone Park	1098	253
XXXVIII.	"In the Basket"	1098	255
XXXIX.	"On the Line"	1098	257
XL.	Freshet Destruction in White River, Washington; and New Growth of Forest Timber	1098	263
XLI.	Cut-Off on Missouri River; and Tree-Felling from River Bank	1098	279

PLATE		PAPER	PAGE
XLII.	Lake Winnibigoshish Dam; and Pine River Dam	1098	299
XLIII.	Leech Lake Dam; and Lake Cheesman Dam	1098	301
XLIV.	Views of Lake George, and the Eastern Slope of the Sierra Nevadas.	1098	381
XLV.	Views in the Sierra Nevadas	1098	383
XLVI.	Cedar Lake, on Cedar River Water-Shed	1098	493
XLVII.	Snow on Evergreen Trees	1098	495

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper. No. 1092

IRRIGATION.

An Informal Discussion at the Annual Convention, June 25th, 1908.

BY MESSRS. GEORGE G. ANDERSON, F. H. NEWELL, J. P. A. MAIGNEN, A. L. FELLOWS, W. W. FOLLETT, GARDNER S. WILLIAMS, F. C. FINKLE, THOMAS H. MEANS, G. N. HOUSTON, RICHARD R. LYMAN, ARTHUR P. DAVIS, AND GEORGE G. ANDERSON.

Mr. Anderson.

GEORGE G. ANDERSON, M. AM. SOC. C. E.—The subject of irrigation presents such a wide field, is of such great importance and magnitude, and of such varied characteristics, that it cannot be treated otherwise than generally in the course of a discussion of ordinary limits. The speaker proposes, therefore, to confine his remarks to a particular field, to a section of Colorado which is typical of the whole State, which is, in large measure, typical of much that marks, or will mark, most other regions which will be reclaimed in the Western States.

Near Denver may be seen some portions of a great agricultural territory which owes its present development solely to irrigation. The valley of the Cache la Poudre River is to-day as fine an agricultural territory devoted to ordinary farming products as can be found, not only in the arid region, but anywhere throughout the United States within the range of its possible products.

It represents the best that has been accomplished within the State of Colorado; what has been done there, can be and is being done throughout the State, and it has been done solely by private enterprise.

The work that has been achieved in that valley has really formed the basis for most other irrigation development, and not only has the practical result been the best and highest type of home building, which Mr. Newell has pointed out as being the ultimate aim of the governmental works of reclamation, but there has been built, out of

Mr. Anderson. the growth of the district, a code of laws which largely forms the foundation of all irrigation law throughout the arid region.

It appears to be difficult, even for the dweller in the arid region, to say nothing of the stranger within the gates, to realize and comprehend fully the significance of the agricultural development of this region, and the future possibilities of similar districts under irrigation; and it is equally difficult to remember and acknowledge the debt owed from one generation to another, and from one region to another, in the process of such evolution as the arid region is now undergoing.

It will not be out of place if a very hasty sketch be given of the progress of irrigation development in Colorado. It has been marked by at least three periods, the individual, the community, and the corporate, and latterly the last has been in large measure resolved back, under recent legal enactments favoring such process, into what is really a form of the community effort.

The first or individual period was contemporaneous with, or followed closely upon, the advent of the gold seekers into the State. It is interesting to note that the dates of the earliest appropriations from the various streams on the eastern slope of the mountains run from 1859 to 1861—Denver was founded in 1858. Either the failure to find gold in paying quantities and the necessity of making a living in some form, or the ready money to be made in raising food for man and beast, and securing enormous prices therefor, drove certain of the pioneers to the less attractive but more certain pursuit of farming by irrigation. It is quite probable that these gained their knowledge of primitive irrigation methods from the Mormons, who undoubtedly introduced it into Utah in or about 1847.

The early irrigation farmers confined their efforts to the construction of small ditches for the reclamation of limited areas on the river bottoms, for the cultivation of hay and the cereals.

The next period was marked by what may be termed the "community" effort, which reached its best development in the Greeley Colony, in or about 1870. The community efforts sought the reclamation of more extended areas, by longer and larger ditches, built by somewhat improved methods, and as the result of the combination of several land owners.

In the latter Seventies and early Eighties the field of development attracted the attention of large corporations and combinations of capital, building larger ditches or canals, reaching out upon the mesas or bench lands, which, prior to this time, were considered unfit for cultivation and altogether inferior to the lands on the bottoms. This somewhat extraordinary view, in the light of later development, was quite extensively entertained of the original projection by ex-Governor Eaton, assisted by what was locally called the "English Company," of

the Larimer and Weld Canal, to irrigate the lands adjoining the now prosperous Town of Eaton. Mr. Anderson.

The corporate investment in large irrigation works, by no means confined to the Poudre River, continued throughout the decade from 1880 to 1890. Two companies, alone, invested, within that period, between $2 000 000 and $3 000 000 each.

About midway in this period, there came a realizing sense of the limited supply of water ordinarily obtainable from the streams, at least on the eastern slope of the mountains.

Under the law, no restriction was placed on the filing of appropriations upon any stream, and there was practically no real knowledge of the ordinary seasonal flow of any stream prior to that time. The earliest continued measurements of stream flow date from about 1885, though some gaugings were made as early as 1883.

It is not surprising, therefore, to find a canal with an appropriation of more than 450 cu. ft. per sec. dating from 1881, on a stream which averages about 840 cu. ft. per sec. in July, and with more than 4 000 cu. ft. per sec. appropriated ahead of it.

At about the same time, the Courts declared that the corporate companies, owners of canals, could not charge a price for water right, or "royalty," but that these canals were merely "common carriers"—that the act of appropriation involved the two separate acts of diversion from the stream and of application to beneficial use. Under such decision, the only revenue that could be derived from such canals was from rentals, and these were under the regulation of the Board of County Commissioners. While the Court subsequently held that these County Commissioners could not fix rentals so low as to be unremunerative, the immediate effect of the decision was disastrous to many of these corporate canal companies.

To that failure, the difficulty of securing at that time sufficiently rapid settlement of the lands tributary to the canal systems undoubtedly contributed. Nearly all farmers at that time were novices in the use of water for irrigation, and all the conditions tended to dissatisfaction and friction.

It is not an unusual experience to find the pioneers in any line of industry meeting with failure, which is finally turned to success by those who follow on the same lines. It has certainly been true that a large number of the unfortunate ventures in irrigation enterprise in Colorado have finally developed into successful undertakings. Many of them were projected before the conditions were ripe; they were merely in advance of the times.

The full realization of the "shortage of water," of the inadequacy of the stream to supply ordinarily all the canals and ditches depending on it, impelled the movement toward the storage of water.

Mention has been made of a canal with an appropriation dating in

Mr. Anderson. 1881, with more than 4 000 cu. ft. per sec. ahead of it, in point of time. It is rarely ever entitled to a supply of water from the direct flow of the stream. Finally realizing this, its owners built the first mountain reservoir on the Cache la Poudre, in 1885, and the storage of water for irrigation purposes had begun.

Since that time, that company has extended its operations to such an extent that it now owns or controls nine large reservoirs, containing more than 20 000 acre-ft., and provides water supply to them by the diversion of the waters of the Laramie and Grand Rivers across the main range. From the position of last on the stream for direct supply, the company has placed its system among the best and most successful in the valley, and more than 40 000 acres of the most productive land in the valley are dependent on it. This has been accomplished, not only by the diversion of water from other streams and by its storage and subsequent use, but also by the "exchange" of water, a system of management of water supply which has resulted in much practical benefit. In its simplest form, it means that a canal company which has stored water in basins below its canal level, and which it cannot again divert into its canal system, will deliver such stored water into another canal, on a lower level, the direct supply to which from the stream will be diverted by the canal company having the stored water.

As illustrative of what can be done in resuscitating an apparently dead venture, and in putting this "exchange of water" into practical and economical form, some reference may be made to the North Poudre Irrigation Canal. This canal was originally started in the early Eighties, and suffered temporary disaster about 1886.

The canal took its supply—merely flood waters—from the North Fork of the Poudre, and embraced about six reservoirs, with a total capacity of about 10 000 acre-ft. None of this was available for the lands tributary to the canal, and was only valuable for exchange. Mr. B. D. Sanborn, a well-known irrigationist, secured the system, and early in 1901 commenced the construction of the Fossil Creek Reservoir, which could impound the natural flow and flood waters of Fossil Creek, and could also be supplied from the flood waters of the Poudre River, by an inlet canal some 5 miles long. This reservoir is very remote from the other reservoirs of the system, and is on the opposite side of the river. It, also, was purely an "exchange water" proposition, and dependent on flood waters, and at its conception was met with the opposition of most of the best informed irrigationists in the valley, for several reasons.

The reservoir was built, however, notwithstanding considerable financial difficulty, and has proved a financial success. It is usually filled with water, and, as a result, the North Poudre ditch usually gets water through the irrigation season; and, largely on that account, the

fine section around Wellington has been developed, and raises the valuable late crops that have added so materially to the prosperity of the region. The reservoir has a capacity of about 11 000 acre-ft. Mr. Anderson.

Taking the reservoirs dependent on the Poudre River alone, there are more than twenty-five in operation, with a capacity aggregating about 100 000 acre-ft.

Some interesting details of these aids to irrigation are given in Bulletins 92 and 134, of the Office of Experiment Stations of the United States Department of Agriculture. In the latter, much consideration is given to the character and value of crops raised by the aid of these reservoirs, and this important statement is made (date 1903):

"The best estimates give $1 000 000 as the worth of these reservoirs to the Cache la Poudre Valley *each year.*"

In Mr. Tonge's "Handbook of Colorado Resources," the area of agricultural land in Weld County alone is given as 223 218 acres, with a valuation of $4 022 870.

In the introduction to Bulletin No. 92, dated December 15th, 1900, Mr. A. C. True says:

"In the Cache la Poudre Valley a series of reservoirs has been constructed by *local and individual enterprise,* which in connection with a system of rotation in the use of water, has resulted in doubling the area capable of being irrigated by the canals alone and in securing more thorough and effective irrigation than is usual without the aid of storage reservoirs. This account of the experience of the Cache la Poudre Valley in the construction and use of storage reservoirs has been prepared and is recommended for publication in the belief that it will prove valuable to many other localities, not only in Colorado but in other arid States."

And in his introduction to the same Bulletin, Colonel E. S. Nettleton, the author, the most prominent irrigation engineer in the early development of the canal system of Colorado, says:

"Ten years only have been required to build up the most complete system of storage in the United States. This has not been accomplished by a large expenditure of money, nor because of unusually favorable locations for reservoirs, nor was it wholly by accident that the people of this valley took up this line of irrigation development. Conditions forced them into it. They did not wait for the general government or the state to build reservoirs for them. * * * While this system is by no means completed, the owners have already reaped much larger rewards for their labors than they expected, reaching into the millions of dollars.

"Although the necessity for storage reservoirs and their utility and benefits are generally recognized, but few people outside of northern Colorado are aware of what has been accomplished in that locality by the utilization of small things or of the ingenuity displayed in making the most of them."

Mr. Anderson. And, in his conclusions, he makes the following remarks:

"Exchange of water facilitates its distribution and amplifies its use."

"The concert of action in the exchange of water appears to have lessened the number of legal conflicts."

and

"Greater economy in the application of water is attained by alternating rather than pro rating in times of scarcity, both among canals and among users from canals."

And he could well have added, what the experience of the years since he wrote the Bulletin has proved beyond peradventure, that the storage of water, by itself, in the sense of increased security to the water user and the certainty of its availability for application just when needed, has materially aided in the actual economy in the use of water itself, to which feature reference will be made later.

About 1896 Captain Chittenden, for the United States Government, examined, among others, two reservoir sites in the State of Colorado, both of which it might have been thought were beyond the reach of private enterprise. One was then called the Goose Creek Site, on the South Platte River; the other was Boyd Lake, tributary to the Big Thompson River.

The first was substantially constructed as the private enterprise of the Denver Union Water Company, and is now utilized for the storage of water for the domestic supply of the City of Denver.

Regarding the Boyd Lake enterprise, some interesting details may be given. A small section of it, known as the Seven Lakes, was developed some years ago as a storage reservoir for irrigation purposes as the private enterprise of Mr. B. D. Sanborn. In connection with this reservoir, Mr. Sanborn held some shares in two ditches which could feed it, and in an effort to store such ditch water, a litigation ensued which has far-reaching effects upon the irrigation interests of the State, and the speaker may be pardoned for a brief reference thereto.

It had previously been held by the Courts that, for flood waters and the winter flow of the stream, ditches with solely reservoir appropriations, or appropriations for the storage of water, had priority for filling over ditches with appropriations simply for direct supply.

This decision was used to prevent the Seven Lakes Reservoir from storing in the basin any of the water represented by its shares in the ditches during the irrigation season. The reservoir company did not claim the right to make any invasion on the river, but sought to have the right to change the character of farming from early crops, such as wheat and alfalfa, to late and more profitable crops, such as beets and potatoes, and to store in the reservoir in the early part of the season—May, June, and July—their *pro rata* share of water in

direct supply to use later in the season, and in this they were finally upheld by the Courts. Mr. Anderson.

It has been charged that Court decisions in irrigation matters have been inconsistent, but consistency may mean stagnation, inconsistency may mean marching in the line of progress and development.

Seven Lakes Reservoir has a capacity of nearly 10 000, and can be developed to about 14 000 acre-ft. Boyd Lake is a very large basin, covering more than 2 000 acres at high-water line, with a depth of 68 ft. It is about 4 miles long and 1 mile wide, and its capacity is about 55 000 acre-ft.

There was much reason to believe it to be larger than any available water supply, but Mr. Sanborn has developed it, and in its first year there was stored in it more than 30 000 acre-ft. The waters stored are to be used in exchange also—and at present the reservoir is in the ownership of one individual, no arrangements having been completed for a reservoir company, and there is some consideration of utilizing it in connection with power development.

These developments are referred to as examples of the work of private enterprise prior to 1901. It is not intended that they should include all the work done by such, not even in the district specially considered.

It may be well to note the development of the Great Plains Reservoir system in the Arkansas Valley, with a capacity of about 264 000 acre-ft., as well as the Twin Lakes, the Sugar Loaf, and others.

The year 1901 has been mentioned, as that marks the period of another irrigation era in the districts under consideration. At about that time the introduction of the sugar beet and the demonstration of its adaptability to this district practically revolutionized conditions, in relation to water, to crops, and to values.

At about that time, also, some legislative enactments were passed which have given an impetus to further development in the construction of ditches and reservoirs.

The Carey Act, approved in 1894, empowers the Secretary of the Interior, with the approval of the President, to contract and agree to patent to States having desert lands, not to exceed 1 000 000 acres of such lands under certain conditions.

The Colorado Legislature, in 1895, accepted the conditions, and the grants of land to the State, under the provisions of the Act of Congress, and provided for the manner in which the irrigation, reclamation, occupation, and disposal of the same should be carried out.

The last Report of the State Engineer of Colorado states that three companies are taking advantage of this act, the largest making application for about 38 000 acres of land, with an estimated expenditure for works of more than $200 000.

Mr. Anderson. An Irrigation District Act was passed by the Colorado Legislature in 1901, and amended in 1905, and, under its provisions, several large undertakings have been completed, and a number are under way. The act gives such districts the power of quasi-municipal corporations, the right to construct or to purchase canals and reservoirs, to operate them, and to issue bonds for these purposes, such bonds constituting a lien upon the real estate within the district.

It practically provides municipal ownership, and by it the water users are enabled to combine for their own direct interest, and, with intelligent co-operation and management, the best results are likely to follow upon its extended adoption.

Through the energy mainly of one man, Mr. D. A. Camfield, the following districts have been organized, and the works completed since 1902:

	Acres.
Fort Morgan District	15 000
Bijou District	40 000
Green City	2 000
Julesburg	30 000
Riverside	60 000
Hillrose	20 000
Montezuma	55 000
	232 000

It is understood that more than $3 000 000 have been expended in the construction of these various enterprises.

In addition, the same gentleman and his associates have under way two districts, the Laramie Poudre, with 100 000 acres, and the North Sterling, with 80 000 acres, and an enterprise adjoining the City of Denver which will reclaim probably 60 000 acres.

Further, in the last Report of the State Engineer, there are three irrigation districts other than those already mentioned, in which bonds have been sold for $560 000 on 28 200 acres; and, since the date of that report, further bonds have been sold by the Otero Irrigation District for the construction of a reservoir on the upper Arkansas River.

By private enterprise, outside of the Carey and Irrigation District Acts, 50 000 additional acres in Weld County have been brought under irrigation by the extension of the Larimer and Weld Canal, the Greeley No. 2, and the Pierce Lateral, and by the extension of the Larimer County Canal; and there is also the very extensive reservoir undertaking in close proximity to Denver, known as Standly Reservoir.

It is also well known that other enterprises, mostly under the District Act, are in progress, the details of which it is not possible to give at this time.

It is not intended that this list should be exhaustive or attempt to

state the total expenditure contemplated, nor to give the present area now under cultivation by irrigation within the State, or the cost of the works which have made that possible—or the value of the reclaimed area. The only purpose is to indicate the extent, character, and value of the work which has been carried out and will be carried out by private enterprise. Mr. Anderson.

Within a reasonable time, and with reasonable conditions which are now apparently provided, it is not too much to say that private enterprise will undertake the conservation of all the waters on the eastern slope of the Rockies. There have been years, and those of moderate flood, in which all the waters of the Poudre River have been conserved and economically applied to beneficial purposes, and the steady extension of the enterprises in that valley indicate that ere long the maximum floods will be conserved in the same way. With the projects outlined on the South Platte, the same conditions will soon prevail in the immediate vicinity of Denver.

The various stages of irrigation development outlined at the outset inevitably call for some remarks on the character of the construction which then obtained. In the earliest days it was, naturally, of the crudest, the gradient of the ditch being developed either in the primitive Mexican way of allowing the water to find its course, or the bed of the ditch was laid out with the spirit level or triangle. Better methods obtained as the plans enlarged, but the critical observer in the Poudre Valley and elsewhere will still see parallel ditches, unnecessarily heavy gradients and distinctly bad alignment. It is not too much to say that these conditions are materially improving, that the engineer is permitted more scope, and that the projectors look for and demand a better character of construction throughout. Much more permanent work is being done than ever before, and the tendency is steadily toward betterment rather than otherwise, though the private investor looks for and expects marked economy in all lines, and the engineer has to regard carefully the returns on the expenditure.

In the past, the most serious error has been due to the projection and construction of large canals from rivers the normal water supply of which had previously been exhausted, and that error, not solely—and probably rarely—the engineer's, was due, as has been pointed out, to the lack of real information as to stream flow.

There has been a very marked improvement since 1887, but the best that is to be had to-day is far from being as complete or as accurate as is desirable. In view of the development of storage and of power-plants, accurate knowledge is required of the flow of the stream for the whole season. At the present time, gaugings are ordinarily maintained for the irrigation season only.

The State authorities are crippled by the lack of funds to carry out the work properly and fully, and it is evidently impossible to

Mr. Anderson. arouse the legislators to make a sufficient increase of appropriations for this purpose.

Co-operation has been had at times with the hydrographic branch of the United States Geological Survey, and even that co-operation has been seriously threatened, as the funds at the disposal of the Survey are at all times inadequate for the work.

The importance of this matter to all engineers must be so apparent that it cannot require anything further than mere mention of the matter to secure the active assistance of the Society, individually and as a body, to secure, for the proper branch of the Federal Service, sufficient appropriations to maintain continued and accurate gaugings.

There is one gratifying condition in the present irrigation situation in Colorado, as compared with a generation ago, and that is the great progress which has been made in the use, and the economy in the use, of water by the user himself. It is not too much to say that the approach to a reasonable and low duty of water has been almost wholly due to the user himself, to the greater intelligence he displays in its use, and the sense of the resulting benefit to every interest affected. And that, again, is due to the greater reliance on storage, the greater sense of security storage conveys to the user, and to the sense of personal and pecuniary profit thereby.

The speaker trusts that in these remarks, hastily prepared as they have been, he has been able to bring eastern engineers into closer intimacy with the subject so vital to those living in the arid region, and to give local engineers an opportunity to discuss still further the subject that is ever old and ever new.

Mr. Newell. F. H. NEWELL, M. AM. SOC. C. E.—The object of water storage and distribution, for irrigation or for industrial purposes, is to make homes for citizens. This is the underlying consideration in the passage of all the Acts of Congress which have to do with the reclamation of the public domain, either by private, corporate or public funds. It is the basal reason urged by promoters or by public-spirited men who favor any reclamation project, large or small, or whether conceived for the purpose of making money or not. The argument used to attract general interest is that homes will be made, population increased, values will rise, and all corelated investments will be made more secure, because of the fact that these homes will be created and production will be stimulated.

The stability and permanence of the commonwealth are assured by the conservation of water resources which otherwise would go to waste. The destructive floods and the excess water of the streams are held in reservoirs. The stored waters when needed are put to beneficial use upon lands which without them would lie desolate. Men otherwise unemployed are put to work, and are enabled to become owners of homes. Water storage is thus one of the first and most

obvious of the many lines of conservation of the resources of the nation. Mr. Newell.

Conservation has come to be recognized at the beginning of this century as the great principle to be followed. Exploitation has characterized the last century. It has been carried to a point where serious-minded men are beginning to wonder whether it is not time to call a halt and take account of stock to see whether the resources of the nation are adequate, under the present wasteful methods, to realize the great promises which the future should hold in store. The President of the United States has taken up this matter. He has called a conference of the Governors of all the States, and this conference has gone upon record as declaring the firm conviction that conservation of our natural resources is a subject of transcendent importance which should engage unremittingly the attention of the nation, the States, and the people in earnest co-operation. This is a recognition of what has been long prominent in the minds of engineers; in fact, it may be said that this conservation movement has been initiated by the engineers who, from their training, have come to regard the conservation of waste as the great element of success. Our "captains of industry" have demonstrated this in their great combinations, where it is asserted that success is attained not so much by processes or invention as by the economies which are possible in operations on a large scale through the saving of the waste products and through the working up of the by-products into profitable output.

In considering, therefore, the question of water storage and distribution, we are simply keeping in line with the great movements of the present day, both in corporate and governmental affairs. The sure foundation upon which only success can be assured is a full knowledge of the facts. If we are intelligently to conserve any waste resources, we must acquire the most complete knowledge available concerning the matter in hand and all of the limiting circumstances. In taking up water storage, therefore, the first consideration is to obtain accurate facts concerning the topography of the country, its hydrographic relations, and the political or human elements, such as ownership of lands and of vested rights. We must obtain by actual observation and surveys on the ground all facts which are available, and even with all the physical data which we can obtain there must be a notable margin of uncertainty which can only be bridged by the use of sound judgment based on wide experience.

The lack of this full knowledge, so necessary for intelligent conservation of water, has wrecked many a brilliantly conceived enterprise. It is unnecessary to relate the details of any cases; the memory of every engineer who has reached middle life is stored with instances where enthusiasm has been substituted for knowledge, and good intentions have paved the way to bankruptcy. A recognition of this fact

Mr. Newell. has led the Government, in its effort at reclamation through water conservation, to go into preliminary examinations with a thoroughness which at times has seemed superfluous, but which, almost invariably, has been shown to be not only necessary, but perhaps has not been fully adequate for the solution of all the problems which have ultimately arisen.

The work of the Government in water storage, as a rule, has been preceded, as far as possible, by topographic surveys of the drainage area and of the lands which are to be irrigated. This has been accompanied by hydrographic surveys carried on by men of experience who, while the topographers were making maps, have measured the flow of water in the streams day by day and season after season, and have obtained all available information concerning the water supply from the time it reaches the ground until it disappears or has passed beyond control.

The methods of topographic and hydrographic surveying necessary for water conservation have been developed in accordance with western conditions. The United States Geological Survey was authorized in 1888 to investigate the extent to which the arid lands might be reclaimed, and there has grown up in the twenty years since that time a highly developed system by which results have been obtained economically and effectively. Both of these may now be regarded as highly specialized lines of work in which well-educated engineers are making a livelihood. Without the continuity of purpose and the broad field of work made possible by the Government, it would not be practicable to perfect the existing systems.

The information obtained by the topographic and hydrographic examinations of the Geological Survey has been utilized by the engineers of the Reclamation Service, in the preparation of designs for works, such as storage or diversion dams, head-gates, and canals suitable for holding the excess water or diverting it to lands where it can be used. There has thus arisen a need of experts in a field distinct from that of topographers and hydrographers, namely, men who have had experience in the storage and distribution of water, not merely from the engineering side, but also from the so-called practical or human side. There has thus been evolved by degrees the characteristic designing and constructing work of the Reclamation Service, with the subsequent requirements of maintenance and operation.

As we progress in the preparation of plans and reach the point where it is necessary to lay out systems of distributing water to the lands, a high degree of technical skill is not only requisite, but to this must be added for success a knowledge of human nature and of human institutions, laws, and court decisions. As we approach the place where the water is actually turned to the farm and distributed to the individual we meet conditions where the human element becomes more

and more prominent, and where the relations of man to man and to the community in general must modify very largely the practical considerations of the subject, overshadowing in part many of the simpler engineering details. Academic considerations may be fallacious, and may lead to the ruin of the best theoretical plans. More quarrels can arise in an arid region than on whiskey! There are to be considered, also, of course, important questions relating to the character of land and of products, nearness to markets, and a thousand other details which are not strictly engineering in themselves, and yet their successful handling makes or mars the value of the engineering work. Mr. Newell.

In all cases, whether the structures are built by public or by private funds, the works must ultimately pay for themselves. If built by investors, they must not only pay for themselves, but must yield a reasonable profit and interest upon the investment. If built by the National Government, under the terms of the Reclamation Act, the question of interest or profit does not enter directly, as water is furnished at the estimated cost, including in this the expenses of administration, which must be provided and must be considered carefully in any estimates of the cost of such works. Cost, therefore, is always an important element.

In the structures designed for the storage of water, the primary consideration beyond effectiveness is that of durability. These works must be among the most permanent built by Man, not only because their use will continue forever, but because of the fact that no risks should be taken where so many lives and so much property are involved. Plans for the construction of storage works, while they must be prepared with regard to reasonable economy, must be with a view to being not merely safe but looking safe. People must not merely be told that they are substantial, but when the plain citizen visits the work he must see for himself that there is every indication of the permanency and stability of a great storage dam. It will not do simply to tell him that the work is safe and that his children and his property, located beneath the dam, are in no danger; he must feel, to the very innermost recesses of his consciousness, that the structure is beyond all question.

Water storage may be provided in many ways. The simplest is that provided by Nature in the woods, where the litter on the forest floor holds back the water and serves to regulate the flow of the streams. Complete water storage must begin with the forests on the mountains, and any movement for full conservation of the waters of the country must begin with a full study of forest protection. The policies of the Federal Government have now been determined along this line. As far as can be done at this late date, the National Forests will be preserved for the conservation of the streams having their sources in the mountains of the West.

Mr. Newell. Next to forest conservation comes the consideration of engineering questions of increasing the storage capacity of natural lakes, or of making artificial lakes by closing narrow outlets through which the drainage from some basin of notable size escapes. Here is where begins the large work of the hydraulic engineer in the location, design, and construction of dams. Their character is various. In the vicinity of Denver are to be found almost all the types of dams which have been built by Man, from the rude timber and stone dam of the lumberman through the earth dams, rock dams, and finally concrete structures which characterize the present century.

The distributing works, as a rule, do not require such permanence of construction or massiveness of design as the storage works. They may be modified or rebuilt in accordance with the development of the country. There is required, however, a reasonable permanence in these structures, for around them are grouped all the improvements made by Man in an arid region. The irrigating canals soon serve as a sort of base line delimiting the desert from the irrigated farms. All property values are associated with the irrigating ditch, so that its first location and construction governs all future land values. A correct location may mean prosperity to a large section; an incorrect location may mean permanent loss to the community or otherwise valuable areas of land.

The speaker wishes to express his appreciation of Mr. Anderson's discussion, and to emphasize, if possible, some of the points which he makes, especially as to the position of the engineer in this great work of water storage and conservation. In the early days, as he has pointed out, each farmer could build his ditch according to his own ideas. With the development of the country and the realization that water is limited in quantity, while land is practically unlimited, has come the appreciation of the need of accurate knowledge of the water resources. There is thus a demand for accurate observation, and for skill to utilize the results of experience. In water storage there may be perhaps one of the combinations most dangerous to human life and property. Stored water, like fire, is an excellent servant but a bad master. The States of the West are recognizing this, and are creating or strengthening their State engineering departments, in order that they may supervise the construction of large storage works.

In ordinary construction, if mistakes are made they can usually be rectified, but when the public enters upon this great work of water storage, it must have structures which will outlast the centuries. There should be no possible risk to lives and property resulting either from the direct destruction of the reservoir, the lowlands, or from the indirect loss which follows the loss of the stored water. In this the need of good engineering is coming to be recognized more and more. This meeting in Denver will be of great aid to our professional

friends in the West in strengthening the hands of our local engineers so that they may demand larger recognition of the fact that the Engineer should dictate, rather than follow the desires of the promoter, or of the man who wishes to develop water. In the past the engineers have been compelled to cut too closely to fit the amount of money available. There is coming about a better recognition of the fact that adequate funds must be provided in advance, in order to build structures which will be reasonably permanent, and that this is as important as a full knowledge of the water supply which can be depended upon to fill storage reservoirs. Mr. Newell.

It is interesting to note that the use of temporary material, such as wood, is gradually being done away with in irrigation works, in favor of more permanent construction. This may be called the age of concrete, in Western irrigation development. Hydraulic cement and concrete are being used more and more; concrete flumes, concrete turn-outs, and especially concrete storage dams are being built. This demand for cement is being met by the building of cement mills in different parts of the West, and with the increasing demand there is a lower price. New supplies of raw material are constantly being found; there is hardly a large county in the West where materials are not found favorable for the making of some form of cement. There is danger, however, of going to the extreme. It has been found that some of the smaller concrete structures have failed, or crumbled, and it is necessary that investigations be made as to the cause of failure of some recent concrete work. Such failure is due, presumably, to the strong alkali waters coming in contact with the cement. Chemical reactions, presumably not yet fully understood, take place between the sulphates in the natural waters which are used to a certain extent in irrigation or occur in connection with drainage.

J. P. A. MAIGNEN, ASSOC. AM. SOC. C. E.—This discussion on irrigation has suggested to the speaker a few thoughts which may perhaps not be altogether devoid of interest. It has been stated that in some irrigation works, where the water is pumped from muddy rivers, and where the country to be irrigated is flat, it has been found advisable to construct near the head-gates of the works a settling basin or grit chamber of sufficient capacity to reduce the velocity of flow so as to assure the deposition of the heavy silt. Mr. Maignen.

Would it not be interesting to consider for a moment what is called "mud," and what harm or good it may do in irrigation works? It is evident that stone, gravel, and sand can do no good on the land, but, on the contrary, may do much mischief by accumulating in the channels intended to convey the water. On the other hand, the fine "mud," of organic or inorganic origin, which is light and capable of floating in moving water, is useful, partly to close up leaks in the earth channels and partly to fertilize the soil. Therefore, at all irriga-

Mr. Maignen. tion works taking water which is usually or occasionally muddy, it would appear to be desirable to provide some small works intended to effect the division of these two constitutents of mud—the heavy grit, which is to be prevented from getting into the irrigation system proper, and the light floating loam, which may be allowed to go wherever the water goes.

The second matter of interest is this: The water of rivers is generally soft and particularly suitable for irrigation, but what about ground-water which contains lime and magnesia in solution? The speaker well remembers the great interest taken in the question of water by the Jury on Horticulture at the Paris Exhibition in 1889. The members of that jury were practical men. They knew the difference between watering plants with soft water and with hard water. They knew that the latter chokes the stomata of the leaves, the H_2O is partly evaporated and partly absorbed, but the lime salts are left behind as a deposit, and, if seen through a powerful microscope, would appear like limestone stalagmites. They also knew that hard water applied to the ground to feed the roots is unable to take into solution the organic or inorganic substances which are necessary to the life of the plants, and which soft water easily dissolves. In other words, hard water brings about the anemia of delicate plants by closing the respiratory pores of the leaves and by coagulating or turning to stone the soluble food of the soil. The members of the jury were so much impressed by this fact that they were on the point of recommending the use of distilled water for watering orchids and other delicate house plants. When they found that hard well water could be softened and made practically equal to rain water by softening processes, they showered medals and commendations on the inventors.

The speaker supposes that the National Government, engaged in these great irrigation works, is fully alive to the desirability of having accurate information on the quality as well as on the quantity of water available, and upon its suitability in different regions for raising the various kinds of crops.

When in the East, and previously in England and France, the speaker has often heard it said that the waters of the West were "alkali," but he has not found any one yet able or willing to tell what is meant by "alkali." In England and France water is said to be "hard" or "soft." It is considered "hard" when it contains more than 85 parts per million of bicarbonate of lime, sulphate of lime, carbonate of magnesia, and sulphate of magnesia (counted as carbonate of lime); and "soft" when the total amount of dissolved mineral solids is less than 85 parts. The salts above named can be decomposed, precipitated, and separated from the water by water-softening processes, and this has been done extensively in Europe in order to make

hard water suitable for drinking and for boiler use, for hot-water systems, etc. Mr. Maignen.

Would it not be desirable that the chemists of the National and State Governments, if they have not already done so, should take up the study of "alkali" waters, and determine how far they are objectionable in agriculture, and whether anything can be done to correct them?

The third point suggested is: What is "sour" soil? It is said that a soil is "sour" when it refuses to grow plants. What is the cause of the sterility of such soil? Is it that the roots are "drowned" in water? Is it that the seeds or roots are eaten or decomposed by animalcules or micro-organisms growing in excessively wet soils? Or, is it that the soil itself has been poisoned by the toxines or soluble residue of the metabolism of the plants that have grown on it before, or by the toxines produced by the micro-organisms actually growing in the impoverished soil?

The first of these suppositions is that commonly accepted.

The second was suggested to the speaker by an observation made in the laboratory. Corn had been planted in muddy material with an excess of water. It did not grow, and upon microscopical examination it was found to have been reduced to a jelly-like paste, and worm-like animalcules were seen in proximity to the rotten corn. Was there any relation between the decayed grains and the animalcules?

The third supposition is the object of scientific inquiry now being carried on by the chemists of the Bureau of Soils, United States Department of Agriculture, at Washington, D. C.

If any member can give any information on the subject of "sour" soil, it will surely prove of considerable interest to all.

Another subject may be mentioned. In filtering water and sewage it has been found, over and over again, that coke is an excellent filtering medium, but it has always been deemed too expensive for large plants. Hence it is that sand, gravel, and cinders have been generally chosen. It has occurred to the speaker that if coke is the best material for the purpose, it should be used, and if the cost is too high, that cost should be reduced by finding a new use for the coke after it has done duty in filters.

In these days, when everyone is concerned in the preservation of the "natural resources" of the country, and when the land is being impoverished for want of fertilizing material, why should the mud collected on filters be washed away and returned to the river? Should it not be collected and distributed on the land with care?

Has coke any value as a manure? It should be remembered that the word "manure" comes from the French word, "*manœuvrer*," which means "working by hand" or "tilling." Upon inquiry, the speaker was encouraged to study this feature, and he thinks that he

Mr. Maignen. can answer in the affirmative. He believes that new coke has a value, as a manure and as a soil sweetener, at least equal to its cost, and that when it is charged with "mud" from water filters or sewage plants, it has a value in excess of its cost.

"It improves the physical condition of the soil, together with its water-holding capacity, particularly on heavy clays."

By helping to darken the soil, it "makes it more absorptive of the sun's rays and therefore warmer."

New coke contains 56% of cellular space. This cellular space absorbs water and gases in a concentrated form, and gives them up later as required. If to these natural qualities are added the nitrogenous matters derived from the solid residue of water or sewage filtration, the result is a product likely to be of some value to agriculture.

The speaker has used coke in several filter plants, but more particularly in what is known as the Belmont Preliminary Filter at Philadelphia, dealing with 40 000 000 gal. of water daily. Experiments made with the spent coke of this filter plant have satisfied him of the correctness of the above views.

The question of the color of the soil is exceedingly interesting. In some of the books on agriculture may be found the statement that dark soils may be 14° warmer than light soils. One day, the temperature being below 40°, the speaker put his hand on a tuft of black top soil which had been exposed to the rays of the sun for a few hours. The earthy material warmed his hand. Coming back to the same spot a few hours later, the speaker suggested to a friend that he should put his hand on a piece of coal which lay on the ground. The coal warmed his hand. He turned the piece of coal upside down, and found that the under surface was warmer than the upper surface, and very much warmer than the surrounding atmosphere.

Many have heard of the experiment made by Benjamin Franklin. He put a black cloth on a piece of ice and the sun's rays melted the ice quickly. He put a white cloth on another piece of ice under the same conditions, and the ice did not melt for a long time. This evidently shows that black absorbs the sun's rays more than white.

Another observation made by the speaker may be worthy of record at this time. At the filter plant designed by him for Lancaster, Pa., which has now been working for some years, a somewhat curious phenomenon was observed which may give room for thought and discussion.

The filter plant is composed of fifteen beds, 16 ft. wide and 150 ft. long, and filled with sand. On seven of the beds a coating of fine coke had been deposited on the surface of the sand. The coating was not more than $\frac{1}{16}$ in. thick, and the coke material used was as

fine as lampblack—the surface looked black. Seven of the other beds had no coke, the sand being exposed to the sun's rays. There was the same depth of water above the sand in all the filters—about 18 in. The plant was put in service at the end of April. The filter beds were uncovered, so that the full sunlight could act on the water. After a few days, the seven beds which had no coke were literally covered with a luxuriant growth of algæ, like a forest of diminutive pine trees; the whole surface was green, but there was not the slightest trace of algæ or green in the seven beds which had the coke. The coke of some of the sterile beds was scratched in spots so that some of the sand was exposed to the action of the light; in the next day or two algæ grew over the exposed sand spots and not where the coke film was intact. Mr. Maignen.

What caused the difference? The water was the same, the sand was the same, the exposure was the same, the only difference being the film of coke. Were the coke filters sterile because the black material absorbed the sun's rays, while the exposed sand in the other filters reflected them? The speaker can offer no reasonable explanation. He simply states the fact for further investigation.

Another phenomenon of the same nature occurred at South Bethlehem, Pa. In a filtered-water basin, the walls were made of rip-rap. These stones had become black from the soot of passing locomotives. The superintendent of the water-works, thinking that he would show off the beauty of the filtered water, whitewashed the stones above and below the water level. A few days afterward a beautiful crop of green algæ grew on the whitewashed stones which were under the water, and gave some anxiety lest they should ultimately give a bad taste to the filtered water. After a certain time the soot of the locomotives blackened the stones again, the whitewash disappeared and the algæ disappeared also.

It has been stated, over and over again, that it is necessary to cover reservoirs containing filtered water to protect it from algæ growth. The speaker is not satisfied that this is absolutely necessary. Algæ do not grow in water which is dirty or full of suspended clay, because it may be supposed that the suspended matter prevents the transmission of light, but they grow profusely in clear water.

It has been seen that black appears to be a protection against the growth of algæ. The speaker, therefore, would suggest that further observations be made along these lines. Perhaps it may be found that a coat of black asphaltum paint, applied to the walls and the floor of a reservoir, will protect the water against the growth of algæ. This, of course, would be more economical than roofing. The same kind of experiment might be made with the concrete portion of irrigation works.

A. L. Fellows, Esq.—The conservation and use of water is a subject in which the engineers of the West have more interest than those Mr. Fellows.

Mr. Fellows. of the East. In arid countries, water is the most valuable asset. The West, therefore, is interested in the greatest possible extension and best possible use of its water supply—in fact living depends on it; agriculture, stock interests, and mining industries are to a very great extent dependent on its proper conservation, and the important question naturally arises: What is the best use that can be made of such supply? The problem is a very complicated one. The speaker has considered carefully the discussions on this subject, particularly those by Mr. Anderson and Mr. Follett, each of whom presents many important matters. There are one or two points, however, which the speaker will emphasize to some extent, and also some suggestions which he will add.

A few years ago, a great engineer, Major J. W. Powell, a master in the subject of the conservation and use of water supply, devoted much study to this great question. At the time that he made his well-known recommendations, he had probably studied the subject more thoroughly than any other engineer, particularly with regard to the use of the waters of the West. It was his opinion that the greatest benefit would be derived by allowing the water to be used as many times as possible. For example—taking the Arkansas River as an illustration—he said that its waters should be stored high up in the mountains, for the development of electric power, for mining, for lumber mills, for stamp mills, for the lighting of cities, for transportation lines, and the other innumerable uses of hydro-electric power. Then the water should be stored again in other reservoirs, and passed on down to the plains, where it would serve for irrigation and other agricultural uses. Major Powell said to a Congressional Committee that the waters of the Arkansas should be used where they could be used to the best advantage, which was along the cañon of the Arkansas, about Cañon City, and again about Pueblo; then, by storage on the side streams, they could be used again, for example, in the vicinity of such a valley as that of Rocky Ford, and so on down the river. The same conditions apply to a great many Colorado streams; for example, on the South Platte River there are numerous reservoir sites which may be utilized in the development of hydro-electric power in the mountains, and the water released from these reservoirs and again stored in others may be used to as great advantage, or even greater, in irrigation below.

The situation is greatly complicated, however, by the fact that the priorities of the irrigation ditches—the irrigation rights—are superior, to some extent, in time at least, to the later claims for power purposes; but there are certain features which must be remembered. Water is an asset of such great value in Colorado, and is so indispensable to its prosperity, that it must have the widest and best possible use. The western streams furnish a water supply greater than required by the irrigable lands under them; therefore, in time,

their waters will be carried across the range to a much greater extent than they have been, because they will be more valuable on the eastern than on the western slope. Mr. Fellows.

Attention is called to a suggestion by Mr. Follett in regard to the use of the waters of the Colorado River. In coming centuries the best results in the use of the waters of this river will undoubtedly be obtained by storing them in great reservoirs in the Rocky Mountains, and subsequently equalizing the flow of the Grand, the Green, the Gunnison, the San Juan and other great streams that make up the Colorado. Power will be developed as the result of such storage; the flow of the streams, after being equalized through these reservoirs, will be used in the irrigation of great tracts of land such as those in the vicinity of Grand Junction; then the water will be stored in other reservoirs, perhaps in the cañons of the Green and of the Grand, and then it will be used in the Imperial Valley in the way described by Mr. Follett. The same may be done on the Rio Grande. It is true that there was considerable early use of water on the Rio Grande, but in this, as in other things, "the old order changeth, yielding place to new," and, on this river, also, there must be, in time, the best and most extended use of the water that is possible. It is a natural law, and cannot be repealed. There is a higher type of civilization in the more temperate climates, and there the water will be used to the best advantage.

Another example is the San Luis Valley. The waters, eventually, will be stored in the mountains surrounding this valley, and be used in that locality. There are other important reasons why such an asset as this should be used to the best advantage. The water in such localities will go farther, and will serve more ground; in other words, its duty will be greater, more lands can be irrigated, and, besides, there is the return water from seepage which can be re-utilized.

It is a suprising fact that fully one-third, or in some cases one-half, of the total quantity of water used in irrigation returns to the stream. On the Black River of New Mexico, for example, half the water used for irrigation returns to the stream and is used again. It is clear that such re-use of water would not be possible if it were required that it must be used lower down on the river at the expense of the lands above. The South Platte might be cited as another example, the return waters being about one-third of the total quantity used. If, for example, all the waters of this stream were allowed to flow to the plains of Nebraska, owing to some early priority there, involving necessarily great losses in transit, as well as the impossibility of securing the advantages of return seepage, there would be a tremendous loss to Colorado. The same is true of nearly all the streams of the West, for most of them rise either in Colorado or in Wyoming. Thus, on the Grand River, there is a great surplus of water

Mr. Fellows. going to waste. In the development of Colorado the best possible use of water depends on turning at least a portion of it over to the eastern side of the range. Objections will be made, but it has been done, and it will be done again and again, until that point is reached where the water supply shall have been most fully conserved.

Mr. Follett. W. W. FOLLETT, M. AM. SOC. C. E.—*Imperial Valley.*—Picture to yourselves a desert—a desert so barren, so devoid of life that not a bush, a shrub, a blade of grass, nor even a cactus, can be seen, nor trace of animate nature in any form; a desolation broiling under the pitiless intensity of a semi-tropic sun. Such, seven years ago, was the greater portion of the Salton Desert, in Southern California, and the rest of it was but little better. Its eastern edge was some 40 miles west of the Colorado River, barren sand hills intervening. It was about 40 miles wide and 100 miles long, its lower end extending into Mexico. No fresh water was found within its bounds. Neither man nor beast could cross it without carrying drinking water. In its lowest portion, 287 ft. below sea level, was a deep deposit of salt, showing that it once formed an arm of the Gulf of California, and that, when shut off by the advancing delta of the Colorado River, the sea-water had evaporated.

For many years it had been a dream of several men to turn the waters of the Colorado into this desert for irrigation use, but only one man kept up the fight. Dogged, determined, C. R. Rockwood persisted in his efforts to impart to men with money his confidence in the future of the desert and in the feasibility of his plans.

Referring to the map, Fig. 1, it will be remembered that Mr. Rockwood's scheme was to take water from the Colorado at Hanlon's, about 8 miles below Yuma, Arizona, by a canal the bottom of which would be so far below the river's bed that the water would flow into it without the necessity for a dam. This canal would parallel the river for some 4 miles and then swing away from it and reach an old channel called the Alamo, 8 or 10 miles farther on. Down this channel, which leads to the Salton Sink, he proposed to carry water to a point, afterward named Sharp's Heading, some 35 or 40 miles down stream, or from 45 to 50 miles below Hanlon's. Here an earthen dam was to be built, the water was to be raised to the surface of the country, and a large system of main canals and laterals was to be constructed, by which the whole arable portion of the desert would be covered. Some 600 or 800 sq. miles of the lowest part of it is so salty as to be unfit for cultivation. A portion of this is now occupied by the Salton Sea.

For years Mr. Rockwood's efforts to interest capital were fruitless, but he kept on trying, discouraged but not dismayed by repeated failures. In his dreams, he saw a colony of prosperous homes and fertile farms irrigated by the Colorado's waters, rich with its fertile silt, and he named it the Imperial Valley. How many laughed at him and ridiculed his pretentious name, he alone knows. At last, after many disap-

Mr. Follett.

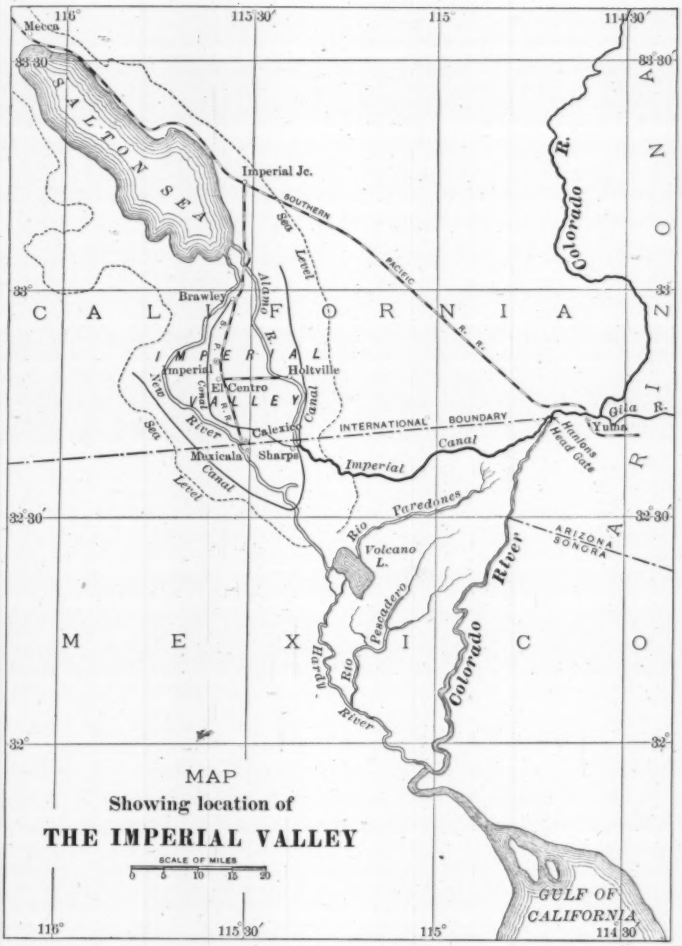


FIG. 1.

Mr. Follett. pointments, he formed, with some associates, the California Development Company, and landed water on the desert in the spring of 1901, and his Imperial Valley sprang from the arid waste under its magic touch. So quickly did settlers come, and so rapidly was land brought into cultivation, that the canal people were at their wits' end to keep up the supply of water. The permanent Hanlon's gate had not been built, only a temporary heading existed, and the canal lacked several feet of being down to the proposed grade. In October, 1904, with about 90 000 acres of land under cultivation and with 10 000 inhabitants in the valley, the heading of the canal began to silt up, and a water famine was imminent. An open cut was made from the river to the canal 4 miles below Hanlon's, and the world-famous Colorado crevasse resulted. It is not intended to go into the details of this crevasse, but, placed in Mr. Rockwood's position, nine out of ten engineers would have opened this cut just as he did—this is said advisedly, the speaker having an intimate knowledge of all the facts in the case.

It is now a matter of history that this crevasse was twice closed and that the second time it was held against the greatest flood which the Colorado has ever carried. These closures were accomplished only after a long struggle, extending over a year or more, and after several attempts had failed. The closures were made by H. T. Cory, M. Am. Soc. C. E. Behind him he had all the resources of a great transcontinental railroad and the help of a most efficient corps of assistants. He fought two veritable battles with the river. During their height, limited trains were side-tracked and held for hours in order that the movement of stone trains might be expedited; everything possible was done by the Southern Pacific Company which would hasten the work.

During all that year, the crevasse and its possible effects if it remained unclosed were exploited by able writers in newspapers, magazines, and proceedings of technical societies, nearly every writer stating or implying that its closure was impossible with the methods being used, and that, unless other supervision intervened, the Imperial Valley was doomed. The men on the ground said nothing, but sawed wood and quarried stone. A few of their friends had abiding faith in them. It would not do to admit even the chance of failure—too much was at stake. The potential value of the valley runs into the hundreds of millions. The crevasse was closed, and will probably remain closed. If, through some freak of the Colorado River, it should again be opened, so again will it be closed.

The Imperial Valley, with two broad and deep scars across its face, where the runaway waters flowed down Alamo and New River channels toward the sink and scoured out gorges from 40 to 60 ft. deep, and as much as 1 000 ft. wide, is still flourishing. At no time during the existence of the crevasse was any of the cultivated valley deprived of water except that portion, some 15 000 acres, which was west of New River,

Mr. Follett.

although there was imminent danger all the time that certain waste-gates at the head of the Alamo would go out and lower the water level to such a point that no land could be irrigated. Heroic, well-directed, and persistent work in the face of great odds held these gates in place.

Only some 2 000 acres of land actually under cultivation were washed away, 400 acres of this being in Mexico.

These two deep channels, from 2 to 10 miles apart, running down through the lowest part of the valley, assure good drainage to the irrigated lands forevermore. Before the crevasse, the lands on the bottom of the valley were in danger of becoming water-logged. Now they are safe from that danger, and this safety alone repays the cost to the valley of the loss of area and all other losses.

Another advantage to the valley accruing from these cuts is the improved opportunity which they offer for the generation of electricity. At Holtville, on the Alamo, there was a power-plant prior to the crevasse, with a fall of some 40 ft.; this is now increased to more than 60 ft. At Calexico, where no chance for power formerly existed, there is now a sheer fall of 60 ft. into the bed of New River. It is evident that this is an opportunity for a large production of power. The tail-water, both on the Alamo and the New, can be picked up and used for irrigation before the Salton Sea is reached.

The valley is now booming. Settlers are going in at the rate of 1 000 per month, and the irrigated area is increasing so rapidly and in so many different places that it is difficult to give correct figures as to this year's area or products. The following statistics are probably under rather than over the facts.

There are between 18 000 and 20 000 people in the valley, and they are watering this season 150 000 acres of land. They will export this year about $3 500 000 of products, besides their home consumption, and, while doing this, they will be incidentally extending the area of cultivated land, planting trees, building homes, and largely increasing their holdings of live stock and personal property. When it is remembered that at least 40% of this area was raw desert land a year ago, the full extent of the twelve months' work is seen.

To haul out this crop, the Southern Pacific Company has built about 80 miles of track south of Imperial Junction. One small city, Imperial, and several thriving towns, Calexico, Brawley, El Centro, and Holtville, are found in the valley.

Look on this picture and then think of the conditions seven years ago, remembering that the valley went backward rather than forward during 1905 and 1906, and you will begin to realize what irrigation means to an arid country.

Nor is the story yet half told. It is a fetish in the orange country of California that oranges will grow only on a sloping porous ground with gravelly subsoil, and it was not supposed that they would mature

Mr. Follett. in the Imperial Valley. Some venturesome man, however, planted a few trees at Imperial, and he has seen ripen on them the finest oranges one ever ate. So that the possibilities of this valley as an orange grove are so great as to become bewildering.

Owing to the advantage of the old Alamo channel, and of the opportunity offered by the rock point at Hanlon's for founding a headgate on bed-rock without a dam across the river, the construction of this enormous canal system has been comparatively cheap, even counting the cost of closing the crevasse. The only permanent structure on the system now, outside of the river levee, is the reinforced concrete heading at Hanlon's. It rests on solid rock, and its capacity is greater than will probably ever be needed. To complete the whole system, with permanent structures, and with canals extended to cover all the land available, will cost, together with the money now expended, less than $5 000 000. This will cover about 400 000 acres in California and 200 000 acres in Mexico—say that, in all, 500 000 acres are eventually irrigated. The cost is seen to be $10 per acre. The Reclamation Service projects run from $25 to $40 per acre. The low cost of the Imperial Valley scheme is due entirely to its favorable location.

Mr. Rockwood's Imperial Valley is no longer a dream. It is a pulsing reality, and is growing more worthy of its name each year. In seven years more it will be a veritable empire.

Lower Rio Grande.—Now, let us go, with the crow, 1 500 miles south of east from Imperial to the lower reaches of the Rio Grande. Here the river has formed a delta extending for 100 miles back from the Gulf of Mexico—a delta of rich dark loam, of almost unknown depth, and of exceeding fertility. The rainfall is not sufficient to mature a crop, but it is enough to cover the ground thickly with a jungle of arid-land vegetation, mesquite, catclaw and ebony trees, cacti of many varieties, and grama-, buffalo- and bunch-grass. Along the low bottom lands of the river are scattered Mexican ranches, where crops are raised from the moisture left in the ground after overflows. These ranches are very old, the Mexicans having lived there for many generations. Their livelihood is a precarious one, because no overflow means no crop, and the river does not top its banks every year.

The Rio Grande in this delta is not as large as the Colorado. Its maximum flood discharge at Brownsville is about 35 000 cu. ft. per sec., as compared with 110 000 cu. ft. per sec. for the Colorado at Yuma. Its minimum flow is seldom less than 1 800 cu. ft. per sec., except in rarely dry years. This is about one-half the minimum of the Colorado. Its mean low-water flow, on which irrigation projects may be based, is from 3 000 to 3 200 cu. ft. per sec.

Although this delta lies some 350 miles farther south than the Imperial Valley, its climate is better. The heat of summer is tempered by the Gulf breezes and probably by the dense covering of vegetation.

Frosts occur in the winter, and sometimes cold "northers" make it disagreeable for a few days, but generally the winter climate is delightful. Mr. Follett.

It has been known for 10 or 12 years that sugar cane grows here luxuriantly and carries a large percentage of sugar. Rice also produces bountifully, if the ground is drained so as to be kept free from alkali. Alfalfa furnishes six or seven cuttings per year, and onions and other garden truck make enormous crops.

Within the past 2 years several different projects have been exploited for pumping water from the river and using it for irrigation. One company is taking out a gravity canal which is to be reinforced by pumping during low water. The Rio Grande forms the boundary between the United States and Mexico, and all the projects here mentioned lie north of the river, or in the United States. There is much more land available than water. Mexico is entitled to half the latter; so that all the land cannot be watered, and the best on each side should be chosen. These delta lands should be preferred to bench lands higher up the river, and, in the United States, perennial irrigation for, say, 150 000 acres and flood irrigation for as much more is the extreme which can be expected.

In addition to raising the crops just mentioned, it may prove to be a good grape and nut country, but this is not yet demonstrated. The frosts will probably preclude the growth of citrus fruits.

With the exception of one company whose works, built some 5 years ago, were mismanaged and proved to be a failure temporarily, none of the sixteen companies, now putting in plants, is more than 2 years old. Indeed, none of the plants is yet completed, yet this year they are watering 15 000 acres, and will water three times as much next year, and the increase will continue for several years. The water is lifted by centrifugal pumps, the lift when the river is low averaging about 16 ft. Pumps having a discharge up to 36 in. are in use. The latter are rated to throw 45 000 gal. per min., or 100 cu. ft. per sec. Wood or oil is used for fuel, and the pumping is done cheaply.

The amount of land now watered is comparatively small, but the increase will be rapid, and the cultivation is intensive. There is direct rail connection with the northern and eastern markets, and hardy vegetables can be grown all the year around.

Last winter this country had a veritable invasion of home seekers. Many bought land, and the boom is on, but it is too soon to show such specific results as does the Imperial Valley. Enough has been done, however, to prove that it will be a great sugar-producing country, and large quantities of other products will be raised. The "back country" for 100 miles north of the river is the great Texas cattle-breeding ground, and there is no reason why this stock should not be fattened on alfalfa grown along the river instead of being shipped north to eat

Mr. Follett. Kansas and Nebraska corn. The potentiality of this section is enormous. Although it has lain dormant for generations, the awakening has come, and progress will now be rapid. Nothing on earth can compare with the wonderful metamorphosis which irrigation development produces.

Both the Imperial Valley and the Brownsville country are being developed by private capital. The Federal Government has not contributed to the work in any way.

The Rio Grande Project.—The Rio Grande's source in Colorado is high up on the Continental Divide. It first runs east and then south through the San Luis Valley, with its 450 000 acres of irrigated land, a plateau from 7 500 to 8 000 ft. above sea level and surrounded by lofty snow-capped mountain ranges several thousand feet higher. The river enters New Mexico, still among the snow mountains, and continues in them until it passes Santa Fé. In the extreme northern end of the San Luis Valley there is an area of some 2 600 sq. miles—about half mountain and half plain—which contributes no run-off to the main river. The remainder of the area above described, as far south as Santa Fé, N. M., has a large snow fall and furnishes much water.

Below Santa Fé, no living streams enter the river for a distance of more than 500 miles. There are several torrential channels which occasionally discharge for a short time large volumes of water heavily loaded with silt. El Paso lies near the lower end of the middle third of this strip. From this point to its mouth the river forms the boundary between the United States and Mexico.

At the lower end of this 500-mile section, there enters from Mexico the Conchos River. This is a torrential stream, discharging occasionally enormous quantities of water. It also has a small perennial flow. Below the Conchos, the river enters a cañon many hundred miles long. In it are numerous springs which, together with the Conchos and two or three other tributaries, make up quite a stream. Its maximum flood waves are at Eagle Pass, where 240 000 cu. ft. per sec. have run for 24 hours. Below, the waves flatten out, and the water ponds in old channels and on low ground, so that, at Brownsville, as before stated, the maximum flood is 35 000 cu. ft. per sec. The total annual discharge here, however, is greater than at Eagle Pass. The total length of channel, from its source to the Gulf of Mexico, measured along its sinuosities, is about 2 000 miles.

In New Mexico, along the Rio Grande and its tributaries, exist the oldest irrigation works on the American Continent which are still in use. When the Spaniards entered New Mexico, more than 350 years ago, they found the Pueblo Indians, living in their many-storied towns and cultivating the land of the valleys, bringing water to it by acequias or irrigating ditches. Many of these are in use to this day. How long these Indians had been there is unknown, but they were then old inhab-

Mr. Follett.

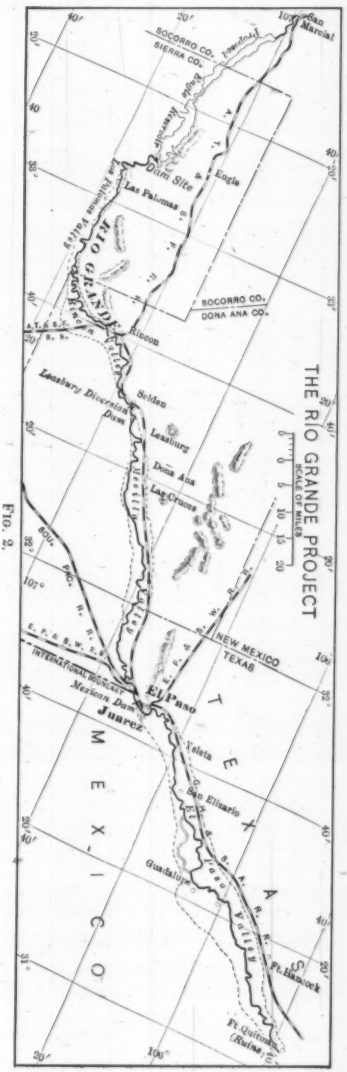


Fig. 2.

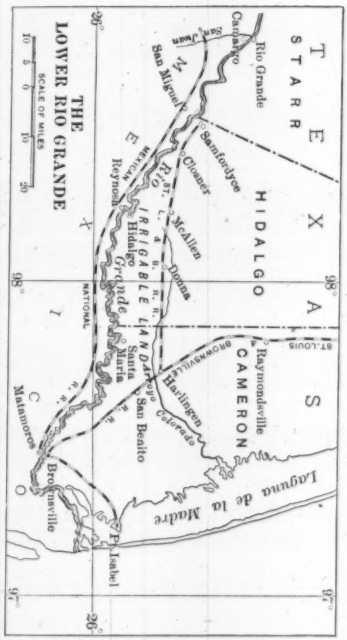


Fig. 3.

Mr. Follett. itants. There are 17 or 18 of these pueblos. The one lowest down the river is at Isleta, about 15 miles below Albuquerque. Below here, as far down as Socorro, ditches were taken out by the Spaniards at an early date, but the Jornada del Muerto and the fertile Mesilla Valley were the stamping ground of the Apache Indians until comparatively recent years. The first ditch in the Mesilla Valley was built in 1844. In the El Paso Valley, below the Mesilla, the Indians were driven out, and irrigation began in the latter part of the sixteenth century.

These settlements were very prosperous until the early Eighties of the nineteenth century. Then the large development of irrigation in the San Luis Valley began to affect the Rio Grande above the mouth of the Conchos, and since that time it has frequently gone dry and remained so for months. No water reached the Conchos for 20 months prior to May, 1900. At El Paso, the river was dry, or practically so, for 227 days out of 365 in 1902. It was practically dry (carrying less than 15 cu. ft. per sec.) from January 9th to August 8th, 1904—213 days of continuous drouth. Of this time the record shows "no flow" (which means less than 2½ cu. ft. per sec. or none) from March 1st to August 8th—161 days. In September, 1896, the speaker saw weeds 2 ft. high growing clear across the bed of the river above the mouth of the Puerco, more than 200 miles above El Paso and about 35 miles below Albuquerque. The river was then dry as far north as Albuquerque. Its flood discharge at El Paso almost reaches 25 000 cu. ft. per sec., and at San Marcial it exceeds 30 000 cu. ft. per sec. The total discharge at El Paso in 1902 was 50 800 acre-ft. In 1903 it was 1 033 000 acre-ft., and in 1905 it was more than 2 000 000 acre-ft.

These figures show that it is here a torrential stream, and that, to obtain the best economic results from the use of its waters for irrigation, they must be stored. Fortunately, there exists an available reservoir site in which can be stored 2 000 000 acre-ft. of water—possibly 2 500 000 acre-ft. This is located about 125 miles above El Paso, 10 miles west of Engle, N. M., and some 60 miles below San Marcial. To build a dam and the necessary distribution system will cost $8 000 000. The land on which this water will be used lies in the Territory of New Mexico, the State of Texas, and the Republic of Mexico. The first cost is too great for individual capital to attempt. The diversity of interests is too complicated for individual or corporate powers to handle. But the Reclamation Service, under the able direction of F. H. Newell, M. Am. Soc. C. E., can handle it, and has taken hold of the enterprise. Through the exertions of one of its best-natured engineers, B. M. Hall, M. Am. Soc. C. E., the antagonisms of many years between the different interests were allayed, and all the communities interested are now working in harmony. Two Water Users' Associations, one in New Mexico and one in Texas, have been legally formed, and the lands have been signed up under the Reclamation Act. All that the land owners can do has been done.

Mr. Follett.

Across the river from El Paso lies the Mexican settlement of Juarez. Many years ago it was noted for its grapes and other fruits, and its large crops of wheat. The records in the old Juarez church show that the Acequia Madre was in existence and doing business more than 300 years ago. When the dry river came, the fruit trees and the vines died for lack of water, and thousands of acres of cultivated land were abandoned. The population dwindled to a fourth of its former number. The Mexicans felt themselves aggrieved in that their water, theirs for centuries, the breath of their life, the one thing which gave value to their lands, had been taken from them. The United States Government recognized their moral, if not legal, claim, and by solemn treaty has agreed to deliver to them, of the water to be stored in the Engle Reservoir, 60 000 acre-ft. each year, and has appropriated from general funds $1 000 000 toward the $8 000 000 required for completing this vast Rio Grande project. The remainder will come from the Reclamation fund when it is needed. Thus, this great enterprise is under way. Already, a diversion dam, costing, with its appurtenances, $200 000, has been built at the head of the Mesilla Valley, and is now in use. At the Engle site a rubble concrete dam, 270 ft. or more from bed-rock to coping, and 1 200 ft. long on top, will, it is hoped, soon begin to grow.

More than 200 000 acres of fertile alluvial land will be watered, and its products, being in the center of the arid country and near large mining camps, will find ready sale. To-day there is an attempt made to irrigate some 50 000 acres of land scattered in the long, narrow valleys stretching from Engle to old Fort Hancock, 175 miles down stream, but the result of planting is uncertain, especially below El Paso, and the sparse population has a precarious livelihood; but, a few years from now—it may be 5 and it may possibly be 10—these valleys will teem with happy homes. The farmer will put seed into the ground with a surety that it will fructify and return a bountiful harvest, because he knows that the water to produce his crop is already stored in the reservoir up the river. His dependence is not in seasonable showers nor in uncertain river flow, but in that stored water, and it is safe.

This reservoir is made so large in proportion to the area to be irrigated for two reasons: First, a succession of dry seasons may necessitate carrying water over for several years. Thus, it would have been necessary to have held some of the 1896 flow until 1902, in order to have exploited fully the capacity of the stream. Second, space must be given for the deposit of silt. While it is believed that plans are developing which will take care of all the sand moving on the bottom of the stream and of a large part of the silt in suspension, carrying it out of the reservoir, some silt will remain, and extra space must be provided for it. It is believed that this reservoir can be constructed so as to supply 200 000 acres indefinitely, and that silt as well as water can be furnished to the land, thus keeping up its fertility.

Do you all realize what these figures mean? Two hundred thou-

Mr. Follett. sand acres does not seem so much when you write it down, but, when you from the East start home, remember that if this land were in a strip one mile wide with the railroad through the center, and all were irrigated, you would ride for more than 300 miles through a veritable garden. If you were to go by water, and were traveling on a steamer drawing 15 ft., these 2 000 000 acre-ft. would furnish water for a channel all the way to New York, with 5 ft. under the keel and a waterway nearly 450 ft. wide.

This will be by far the largest artificial lake in the world. At present an Indian reservoir, which is filled only once in 20 years or so, is the largest, with a capacity of 950 000 acre-ft. Then comes the Assouan Reservoir, on the Nile, which, as now constructed, holds 900 000 acre-ft. When completed, the Roosevelt Dam, now being built by the United States Reclamation Service, on Salt River, in Arizona, will impound 1 300 000 acre-ft. of water, and thus will hold the record of being the largest artificial reservoir in the world, until the completion of the Engle Dam.

A Few Indian Irrigation Works.—For the sake of comparison, let us glance at the reclamation works of far-away India. There the English engineers have built, and are now quietly building, irrigation systems having a magnitude beside which the largest in the United States look almost insignificant, as far as acreage covered, and size and length of canals, are concerned. The speaker has collected the following information from the 1905 edition of Buckley's "Irrigation Works of India."

In 1903, in British India, more than 44 000 000 acres of land were irrigated, of which about 20 000 000 were watered from canals built by the engineers, and from the funds of the British Government. Of this latter area, more than 3 600 000 acres were watered by three canals taken from branches of the Indus, in the Punjab. The Bari Doab, taken from the Ravi, carries 4 500 cu. ft. per sec., and waters 850 000 acres. The Sirhind, taken from the Sutlej, has a capacity of 8 200 cu. ft. per sec., and, in 1903, watered 1 170 000 acres. The Chenab heading, in the river of the same name, has a capacity of 10 800 cu. ft. per sec., and, in 1903, served 1 600 000 acres. Its mean flow during the rainy season was more than 8 000 cu. ft. per sec., and, during the dry season, 6 000 cu. ft. per sec. It is said to have watered in one year 2 000 000 acres, or as much land as is now irrigated in the whole State of Colorado. It covers more than 2 600 000 acres, and cost to build about $10 000 000, or less than $4 per acre. This low cost is doubtless partly due to natural advantages of the country and partly to cheap labor. It paid 21% on its cost in 1903, clear of the cost of collecting rentals and of maintenance.

On the Ganges River, the Upper Ganges Canal carries 8 000 cu. ft. per sec. It serves not only to irrigate 1 300 000 acres of land, but also

acts as a feeder to the Lower Ganges Canal. The latter carries 5 000 cu. ft. per sec., and, with the help of the upper canal, waters more than 1 200 000 acres. Water, taken from the river by the upper canal, is carried 180 miles before it is turned into the lower canal, and then travels 240 miles farther before it is all used. The irrigator on the delta at the junction of the Ganges and Jumna Rivers turns on his land water which has been transported 420 miles in an artificial earthen channel. Mr. Follett.

Up to 1903, the British Government had spent about $150 000 000 on canal systems, or an average of $7.50 per acre for the land actually watered. In that year, it derived an average net revenue of 6.3% on the cost. Many systems were operated at a loss, and will probably be so for many years. They are intended to ameliorate famine conditions. Two large projects were then approved and funds provided for them. These would cover upwards of 5 000 000 acres, and are now doubtless completed and in use.

Stupendous as these projects are, they do not mean so much in proportion to size as do those in the United States in adding to human advancement. It is stated that the Chenab has made available homes for 1 000 000 people—or two inhabitants for every three acres irrigated. Some of the other systems have a denser population, and their construction has served principally to lessen the death rate from famine. They have ameliorated the condition of the natives, but have not brought in so high a civilization as do smaller enterprises in the United States, where homes are made, universities founded, churches built, and all the complexities of a higher civilization set under way. During this Convention will be seen what 40 years have done in reclaiming the desert, and, although the total acreage is less than one-third of that watered by the Chenab alone, a vast addition to the happiness of mankind may be observed.

The Law of Prior Appropriation.—In the humid States the old common law of riparian rights obtains. Every man owning a frontage upon a living stream has the right in perpetuity of undiminished flow in it. He may use the water in any way he wishes, as for power purposes, provided he does not injure his neighbors above by flowing their lands, and provided he returns to the stream below the water practically undiminished in volume.

This law will not serve the arid country, where water, taken from a stream for irrigation, returns no more to it except, in some cases, in greatly diminished volume, as seepage. Should the tenets of riparian law be enforced, irrigation would stop. Therefore, a new principle was evolved from the necessity of the situation—the law of prior appropriation. The water of all streams is declared the property of the public or of the State, subject to appropriation for beneficial use, and he who first appropriates all or a portion of the water of any stream and perfects

Mr. Follett. his claim by putting it to a beneficial use, obtains a legal property right to that water. It becomes his as much as is the land on which he uses it for irrigation, if this be the purpose of his appropriation, and such it usually is.

You may own the land on both banks of a stream for miles, and yet, should you allow its waters to go to waste, a neighbor below you can enter on your land, locate and build a dam and a headgate in the stream, condemn a right-of-way for his ditch across your land, build it, and divert that water to his lands below, and you lose all rights to it.

Where several appropriators take water from the same stream, the one who first took it must have what water he needs, up to the amount of his appropriation, before the second is allowed any, and so on up the list. These rights are determined by different methods in the different States, but they are all called "adjudications." After a stream is adjudicated, the water is distributed among the several ditches by a State official.

Thus far, this adjudication has been confined to that portion of interstate streams which lies in each State, all rights of the State lower down being ignored by the one above it, but there is no logical reason why an imaginary line across a stream should give the land owner above that line a right to take the property of the man below it, whether it be a county, state, or international boundary. For, in an irrigated country, the land has no value without the water, and the property right vests in the latter. If a man's water is taken from him, he is robbed, whether or not an imaginary line crosses the stream of supply between him and the robber.

There are many ramifications of this law, and it is materially modified in different States, but the basic principle applies to the water laws of all the arid and semi-arid States except to those of California. There, the riparian theory ostensibly holds, but it has been modified to such an extent by statutes and court decisions that it is unrecognizable.

Those interested in this phase of irrigation will find the subject fully discussed in "Irrigation Institutions," by Elwood Mead, M. Am. Soc. C. E.*

It has never seemed to the speaker that the storage of water for the development of electrical power and for irrigation go together. The supply of stored water for electrical development must be one which is continuous throughout the whole low-water season of the stream which it supplements. Water stored for irrigation will be used within a comparatively short time. It may be stored and held for several months, or even, in the case of large reservoirs, for years,

*The above paper was read to the meeting of June 24th, 1908; the discussion which follows was contributed by Mr. Follett at the meeting of June 25th, 1908.

and then all used in two or three months. This will not serve for electrical power development. Mr. Follett.

Now, as to seepage: The seepage return in Colorado has been carefully studied by Professor Carpenter and others, and it exists, as has been stated. On the Rio Grande, however, there is no seepage return from irrigation below the San Luis Valley. In that valley there is a small return in some places and a large loss from seepage in others—as on the main Rio Grande between Del Norte and Monte Vista. In the foregoing paper the speaker mentioned having seen weeds growing 2 ft. high across the bed of the Rio Grande below Albuquerque, in September, 1896. During that season, and for 200 years prior to that time, there had been, in the 40 miles of the valley of the river above the point where these weeds were growing, some 20 000 acres of land under cultivation. It had been irrigated every year, and still there was not one drop of seepage return from that irrigation water going into the channel of the stream.

The whole Rio Grande Valley is an alluvial deposit. The river in most places lies on the top of the valley, and the water, once taken from the stream, never comes back. A few days after those weeds were seen, the speaker visited a point, a hundred miles or more down the river, where there was a reef of rock which crossed the river bed and probably forced to the surface all the underflow which might be going down the stream. When visited, there were about 4 cu. ft. per sec. running, the river being dry above that point.

In 1904 Professor Slichter, who has measured the velocity of underground waters in various places for the Reclamation Service, came to El Paso and attempted to measure the velocity of the underflow in the Rio Grande where it runs through "the Pass" just above that town. There the hills shut the river into a space about 350 ft. wide, with bed-rock 70 to 90 ft. below the bed of the stream. He could not detect any velocity.

The question naturally arises: What becomes of the waste water from irrigation and also from overflow? The only answer which the speaker can give is, that it evidently sinks into the ground and is held there until it is evaporated or transpired through growing vegetation. The material of the valley is fine sand and alluvium interspersed with thin layers of clay. Water does not percolate through it at any appreciable rate of speed. The river is a torrential stream, becoming dry at times, and irrigation goes on for only six or seven months of the year. The rainfall is 8 to 10 in. per annum, and the evaporation from a pan in water is about 6 ft. per year plus the rainfall; so that, between floods and between irrigation seasons, the subsurface water is dispersed in the air to such an extent that room is made for the next year's surplus.

In this discussion it has been stated, as a general economic prin-

Mr. Follett. ciple, that water should be stored for the development of electrical power and then used for irrigation, and the inference was that the water was stored but once. When the speaker challenged this statement, it was then said that two reservoirs must be used, one above the power-station and another below, and that the lower reservoir need be only one-third as large as the upper, provided the system could be started off with the lower reservoir full.

After considerable study of the problem, the speaker is unable to accept this statement. He does not believe that the scheme will work in practice, especially on streams whose perennial flow is over-appropriated for direct irrigation and whose flood supply, in seasons of small spring flow, is over-appropriated for storage of water to be used later for irrigation. The first condition obtains on every stream on the eastern slope of the Rockies, south of Wyoming, and the latter exists on many. Perhaps the statement of a concrete example will make the speaker's position plainer.

The Cache à la Poudre, which supplies the Fort Collins and Greeley Country, had a deficient flood flow this spring, and, as a result, the numerous reservoirs on the plains, holding storage rights to flood water, were only one-half to one-third filled. The full capacity of these reservoirs is always needed in August to mature the potato crop and to irrigate alfalfa.

Now, with these conditions existing, assume that a large reservoir had been built up the stream in the mountains for power storage and had been filled with water during the spring of 1908. Under the law of prior appropriation, this water would be the property of the reservoir owners on the plains, as their reservoirs were unfilled. The power company would need the water to supplement the low-water flow of the stream throughout the whole period of small flow. This period runs from the latter part of June or early in July until February or March, and the draft for power on the mountain reservoir should be so proportioned, month by month, as to make the water last for the seven or eight months during which it may be needed.

Owing to the shortage of water, all the plains reservoirs become empty in August, and crops are suffering and dying for want of water. The power reservoir is filled with water to 70% or more of its capacity. This water, had it not been stored there, would have been held in the plains reservoirs and would have been used toward saving the crops. Under these conditions, it is almost certain that the Water Commissioner for that district would compel the power people to turn that water loose, and let it all come down the stream in two or three weeks' time. By September 1st the reservoir would be dry, and the power plant would be crippled for the next six months. No small secondary reservoir would be of any material service.

It may be claimed that this is an exaggerated case. Perhaps it is,

but it illustrates clearly the speaker's position, and is one which may be, and will be, approximated on any stream of the Gulf drainage from the Continental Divide. Mr. Follett.

Where power plants are developed with the storage of flood waters not already appropriated, their operation will result in increasing the perennial flow of the stream below their wheels and so will benefit irrigation. If it is desired to store the flow from the plant after the cropping season is over, for use the following year, this can be done if reservoir sites can be found; but the speaker would consider this an entirely distinct development independent of the power plant, and one which would be properly undertaken by those to be benefited by the storage and not by the power company as such.

GARDNER S. WILLIAMS, M. AM. SOC. C. E.—There seem to be rather conflicting ideas on the matter of return water; but, to some extent, they can be explained quite satisfactorily in the light of what is known of the absorption of water by various kinds of plants, and the variable amount of evaporation from different soils. It may be suggested that in the Rio Grande Valley the quantity of water spread upon the land has not been sufficiently great to leave any excess over that needed by the vegetation and that evaporated directly from the soil; whereas, in other localities there may be so much difference in the situation that the demands of these two agencies for water have left some over to fill up the subterranean basins, and that possibility may account for the difference in the return water from the several drainage areas. It may even happen, as time goes on, if the soil be sufficiently porous, that a part of the water used for irrigation purposes in the Rio Grande Valley will return to the streams. Mr. Williams.

F. C. FINKLE, ESQ.—Mr. Follett has stated that the development of electric power may be greatly restricted, or entirely prohibited, in many sections of the arid region, because of the conflict with irrigation. He bases his conclusion on the conflicting nature of the uses of water from streams for irrigation and power. It is true that water for irrigation must be available during the months of seeding, sprouting, and growing, and that it must be conserved during the remainder of the year. Usually, five or six months of each year cover the irrigation season, and these are during the spring and summer. Throughout the arid West the only exception to this is in the sections of Southern California where citrus fruits or winter fruits and vegetables are grown. For these crops it sometimes becomes necessary to irrigate every month in the year, during seasons of deficient rainfall, or "dry years." Mr. Finkle.

On the other hand, water for power purposes must be continuous throughout the year; must, in fact, be more plentiful in autumn and winter because days are shorter and more power is consumed for illumination.

Mr. Finkle. The mountain streams suitable for developing power have their greatest flow in summer, usually become very low in the fall, and attain their minimum flow in winter. This arrangement is favorable to irrigation, except when the snows melt so rapidly as to cause great floods in the early spring and a scarcity during the summer growing season.

If such streams are equalized, so as to make their use profitable for the development of power, the effect will be two-fold, as far as irrigation is concerned. The large floods may be stored in reservoirs and released when the stream naturally discharges less water than is needed to operate the power-plant. This does not interfere with irrigation. Or, if the power development is planned on a larger scale, it is necessary to store some of the normal spring and summer flow to regulate the streams to a higher flow during the minimum months. This will interfere with irrigation unless measures are taken to return the water thus impounded—when it is necessary for irrigation—at some subsequent time, and it will then have an equal value for that purpose.

Such a result can be accomplished by the use of secondary storage below the tail-race of the power-plant. This will amount to double storage for a part of the water used by the power-plant.

To illustrate: For a stream having a discharge of 200 or 300 cu. ft. per sec. during May, June, July, and August, and a diminished flow, as low as 20 cu. ft. per sec., during December, January, February, and March, it is necessary to store water at the headwaters, so as to regulate it to give a flow of not less than 100 cu. ft. per sec. during the whole year. If the storage is available and accomplishes this, the surplus over 100 cu. ft. per sec., which is demanded continuously for the power-plant, must be stored during May, June, July, and August. Now, if all the water is required for irrigation during these months, it is clear that the storage of any part of it will interfere with its use for that purpose. It will be necessary, therefore, to construct another reservoir, at some point below the tail-race of the power-plant and above the intake of the irrigation canals, by means of which the water used in the power-plant can be impounded during the non-irrigation months, and released during the following irrigation season. This is called a secondary reservoir, and the purpose it accomplishes is called secondary storage. After it is once filled, its operation effectually prevents any conflict between the power and irrigation interests on the stream. This operation merely consists in releasing contemporaneously from the secondary reservoir the same quantity of water as that taken to fill the reservoir above the intake of the power-plant.

During the months of low flow in the stream, the secondary reservoir is again filled from water passing through the power-plant,

which at that time is not demanded for any other purpose than that of generating power. Thus the process becomes an endless chain, by which the natural flow of the stream is maintained for the benefit of irrigation, and at the same time it is regulated for use as required by the power-plant. Mr. Finkle.

No difficulty and interference with irrigation need be anticipated when first filling the secondary reservoir, as this may be done from water flowing during the non-irrigation months, while the power-plant is being constructed.

There are examples of power-plants, where this method is used to harmonize the interests of users for power and irrigation on the same stream.

To illustrate this the speaker can refer to those plants of the Edison Electric Company, of Los Angeles, on Mill Creek, in San Bernardino County, California, known as "Mill Creek No. 1" and "Mill Creek No. 3," which he designed and constructed for that company many years ago.

The entire flow of Mill Creek is used for the irrigation of valuable citrus orchards near Redlands, Cal. These water rights are among the oldest in the State, having been appropriated by the Indians for the irrigation of their gardens and corn fields sometime before 1826. They passed later to the Mexicans and from them to the Americans, being at the present time valued as high as $100 000 for each cubic foot per second of perpetual flow of water.

The use of the water for power would not be profitable unless regulation of some kind by storage could be accomplished, because the flow of the stream is extremely variable and not adapted to the load curve obtainable for a power-plant. Yet no storage could be permitted which would alter the natural discharge of the stream without infringing on these very valuable irrigation water rights.

The problem was solved by constructing a primary reservoir above the head of the force main for the upper power-plant. From this reservoir the water is used through the upper plant, under a head of 1 923 ft., and then through the lower one, under a head of 530 ft. Below the tail-race of the lower plant and above the point of diversion of the "Mill Creek Zanja," which is the main conduit of the irrigation system, is located the secondary reservoir. By means of this reservoir the stream is regulated back to its natural flow.

This system has been in operation for many years, and has worked successfully. No injury has resulted to the irrigators, and the power-plants have not been hampered by conflicts over vested irrigation rights, nor deprived of the water required for their business.

Acting on the same principle, the Eastern Colorado Power Company is now constructing a power-plant on Middle Boulder Creek, about 30 miles from Denver. In connection with this development,

Mr. Finkle. storage reservoirs in the mountains are being constructed to impound water in summer, which will be turned through the conduit to the power-plant for use in winter, when the natural stream flow is wholly insufficient.

In order that the water used for power in winter may not be taken away from land requiring its use for irrigation, the company is preparing to build a secondary reservoir below the power-house. By means of this reservoir, what has already been explained will be accomplished, namely, re-storage of the water used for power in winter and its use for irrigation during the following summer.

A report has been made for a similar power development for the Eastern Colorado Power Company. This is on the Big Thompson River, and also on the eastern slope of the Rocky Mountains. Several excellent reservoir sites in the mountains are available, and locations for two power-plants below these have been recommended. For secondary storage, Boyd Lake Reservoir, referred to by Mr. Anderson, has been selected. This reservoir has been practically completed by Mr. B. D. Sanborn, a Greeley capitalist, who has given an option on a portion of its capacity to be used by the Eastern Colorado Power Company as secondary storage in connection with the Big Thompson power projects.

The principles thus applied to practical use are necessary in carrying out power projects on the eastern slope, in Colorado. The streams flowing from the eastern slope of the Rocky Mountains are either completely used for irrigation, or the demand of the future is so great as to make their conservation for this purpose a necessity. It is apparent, therefore, that power-plants in this region must be planned with double storage.

Time has only permitted a discussion of the general principles involved, but it may well be added, that the secondary storage need not be as large as the primary. This is a detail which must be carefully worked out from the data presented by each individual case.

Mr. Newell has referred to another very important matter for the irrigation engineer, that of concrete work failing under certain conditions.

An instance of this was observed about 10 years ago, at Santa Barbara, Cal., where a concrete pipe became completely disintegrated. The pipe was made originally from the best hydraulic Portland cement, all carefully tested, and the aggregates were of the best quality of sand and gravel. The workmanship was the same as on similar pipes which have been used for more than thirty years and are apparently unaffected by time. Investigation revealed only one possible cause for failure: The soil in which the pipe was laid contained iron pyrites, which by decomposition produced sulphuretted hydrogen, and the presumption is that this affected the cement.

A similar failure of concrete pipe occurred at Cucamonga, Cal., a few years ago. The pipe had been properly constructed, and was laid in a swamp. Examinations of the soil and water revealed only one theory by which the softening of the concrete could be explained. The conclusion that decomposition and fermentation of the vegetable matter in the swamp produced carbon dioxide, which caused the trouble, seemed inevitable. It is known that carbonic acid gas has a strong affinity for lime, and it is supposed that its combination with the lime in the cement produced carbonate of lime. The cement in the pipe had become soft, and resembled talc, or a mixture of clay and limestone dust. To all appearances, it had returned to the state in which it was found before it was burned into cement. Mr. Finkle.

Cement is supposed to be one of the most indestructible materials, and yet it cannot be used under all conditions.

It is well known that steel, iron and wood must be used with great discretion in order to build works of a permanent character. Referring to wood, and particularly as a material for water pipes, it is interesting to recall the paper* by Arthur L. Adams, M. Am. Soc. C. E., regarding the water-works at Astoria, Ore.

The case cited by Mr. Adams is one of several where wooden-stave pipes have been unsuccessful, while there are many other instances in which they have been entirely successful. The failure at Astoria is undoubtedly due to the large quantity of vegetable matter in the soil, which makes it a "muck" soil. This conclusion is borne out by experiments made elsewhere to learn the effect on wood in soils where large quantities of vegetable matter are undergoing decomposition.

Among some of the wood-stave pipes which have proven highly successful are those of the Denver Union Water Company. The soil in which these pipes are laid is only slightly alkaline with chloride and sulphate of sodium, there being no carbonate of sodium. The pipes are also under a heavy pressure, which is favorable to long life by maintaining complete saturation in the wood.

These matters are referred to merely for the purpose of showing the grave responsibility resting on an engineer when he selects materials for use in construction work.

The discussion by Professor Carpenter on alkali is also a matter of much importance to an irrigation engineer. It does not necessarily follow that all land containing alkali, even in considerable quantities, is useless. The most common forms of alkali in California are sulphate of sodium and chloride of sodium. These are not harmful to the growth of many crops, and some such alkaline land, as for example in the great Imperial Valley, is extremely productive and valuable; but it is important to know that it is necessary to cultivate such land with intelligence, after it is brought under irrigation. Instances have

* *Transactions*, Am. Soc. C. E., Vol. LVIII, p. 65.

Mr. Finkle. been observed where such land has been heavily fertilized with manure, or where it has been plowed, turning under large amounts of vegetable matter, and then irrigated. Invariably, this results in fermentation and the production of carbonic acid gas in the soil. As carbon dioxide has a greater affinity for sodium than either sulphuric acid gas or chlorine, the sulphates and chlorides of sodium are converted into carbonate of sodium, which is a very destructive alkali and renders the land worthless.

Alkali land which may thus be impaired should be cultivated with as little humus for fertilizing it as possible, and should not be oversaturated with irrigation water, but kept as dry as possible, consistent with the production of crops, and must at all times be well cultivated in order to aerate the soil.

Mr. Means. THOMAS H. MEANS, ASSOC. M. AM. SOC. C. E. (by letter).—Irrigation is now the vital problem before the people of the western part of the United States. From the early individual effort, through corporation and State extension, the problem of irrigation has at last taken on a National aspect, and the future hope of the West lies in National irrigation. The majority of easily built systems have been taken up, leaving only the more expensive works which are beyond the means of corporations. Home-building is the great problem in the West; here lie the great grazing areas, the forests, the great mineral deposits of the United States, and large areas of the most fertile soil. The high mountains offer many opportunities for power development and, as these power propositions are taken up, manufacturing will be started.

It is gradually creeping into the minds of Western men that Government ownership and control of such resources as water and forest offer the best means of managing and conserving these resources for the good of the whole people for the longest time, and as the people of the West come in personal contact with the operations of the Forest Service and Reclamation Service, the great prejudices against Government ownership and management are disappearing.

One phase of home-building, that is, power development, has not been considered as seriously as seems advisable. Such development provides means of employment in manufacturing and, consequently, home-building for factory operatives.

To bring about the greatest development and the making of the greatest number of homes, irrigation and power development should be under one control. When there comes a conflict of interests, it becomes a question of calculation of which use of the water will return the most to the people and permit the greatest development of homes. An interesting method of calculating the relative value of water for power and for irrigation has been suggested by A. P. Davis, M. Am. Soc. C. E. If the value of 1 h.p. averages 1 cent per hour, and the

returns from the land be $25 per acre, and it be assumed that 50% of the theoretic power can be realized and sold, and that 3 acre-ft. of water are required for irrigating 1 acre of land, it is interesting to determine the height which the water necessary to irrigate 1 acre of land would have to be dropped before it was as valuable for power as for irrigation. Under the conditions just stated, the water will have to be dropped 1 120 ft. to bring the same returns for power as for irrigation. Where the returns from irrigation are greater than those given, the height which water must be dropped is greater, and where power is correspondingly higher in price, the height is less. While these calculations are crude, and, perhaps, do not fit conditions in any district of the West, they serve to show that where water is used for power, to the exclusion of irrigation, the power must either be very valuable or the fall considerable. Where, however, the water can be used for irrigation below the power-house or caught in storage reservoirs, the development of every possible horse-power is a duty which belongs to the organization having charge of the development of the stream. Mr. Means.

If the irrigation possibilities of a given stream are in the hands of one organization, and the power possibilities left for any one to secure, the best development of resources and the home-building, so desirable in the West, can never be carried to their fullest extent. Already hundreds of instances can be pointed out where power development of previous years is now standing in the way of the fullest development of home-building by irrigation, and many instances are on record where large power companies have control of power possibilities with no intention of development, holding the rights only to keep out competitors. Future power rights should be granted only to parties who will immediately develop the right granted, and grants should be made only for a term of years. Every power right granted should be approved by that organization having in charge the development of the stream in question, and should only be granted after careful investigation to determine whether such right will ever interfere with more valuable future developments. The man who tacks a little piece of paper on a tree, thereon claiming power privileges, should never have the right without development, but should be required to act promptly or to turn the right back to the Government for development.

It would seem that the time is almost ripe for a National Department of Natural Resources, in whose charge will be placed mining, forest, irrigation, grazing, and other natural resources now belonging to the people, and the title to which should never leave the people.

Irrigation consists of a great deal more than building storage dams and digging ditches, that water may run down hill in an orderly manner. Many dams are built, thousands of miles of ditches are in

Mr. Means. operation, and yet there are many little kinks in the problem which must be straightened out before the greatest success can be attained. These are now the problems before the West. Many men have found themselves in charge of well-built irrigation systems with good water supply and thousands of acres of fertile soil, yet years of earnest effort were required before the system could be considered a success. The problem is largely a human one. The success of many an irrigated country has resulted only after many individual failures, and sometimes two or three groups of settlers have come and gone before entire success has been obtained, yet the first man had the same opportunities for success as the man who finally succeeded, and the fault was largely his own.

A Government irrigation project will have more of these difficulties to contend with than the project under private management, for the man attracted by the Government is of an entirely different type from the man who selects a private irrigation system. Moreover, the Government cannot select its settlers as a private company does, but must accept the water-right application of any man who has the money for a first payment. The Government project attracts the man who is looking for the Government to give him something, for the idea of a "homestead" is a "free home." No more mistaken idea was ever conceived. An irrigation homestead is not free; there are definite financial obligations to be met, and the settler must have money or crops must be grown and sold before these obligations can be met. The settler must either have the capital to meet these obligations or the experience to enable him to grow crops at once.

Government irrigation has been so widely advertised in papers and magazines, and the glories of a farm in the free West have been painted in such true pictures that many city-bred men are coming west. The man in the gloomy back office in Chicago, who reads of the sunshine and freedom of the West, where a man can wear overalls and a flannel shirt and yet be respected, often overlooks the fact that he will have to wield the business end of a pitchfork in the hot sun, instead of a pen beneath the cheerful buzz of an electric fan. He thinks of the cool shade of a grape arbor and has an idea that, by sitting on the back porch, he can pull a string which will lift a gate and irrigate the back lot. When he gets into the real practice of irrigation, and his ditch breaks and drowns half his crop and the other half dries up before the ditch is fixed, and his whole year's work is gone; or when, in the middle of a hot afternoon, the blinding sweat is pouring over his face as he pitches a few more tons of hay on the wagon, he thinks of that Chicago office with the electric fan as one of the most attractive of places, and it is no wonder he becomes a little bit discouraged.

A statement of this kind is made to show some of the difficulties

in the way of Government irrigation. In spite of these, Government irrigation is now a success and promises to become all the more a success. The future of the West depends on it, and far-seeing men look to the time when the control of the natural resources of the country will be guarded by an impartial set of men, working for posterity as well as for the people of to-day. Mr. Means.

G. N. HOUSTON, ASSOC. M. AM. SOC. C. E. (by letter).—Irrigation structures in Colorado are in the transition period mentioned by Mr. Newell. The old timber structures are giving way to steel and concrete. Mr. Houston.

In the spring of 1906 the writer was called on to suggest some method of protecting the embankment of Terry Lake, a reservoir owned by the Larimer and Weld Reservoir Company, and located about one mile north of Fort Collins, Colo.

SKETCHES SHOWING METHOD OF WAVE PROTECTION
ON EMBANKMENTS OF TERRY LAKE RESERVOIR, FORT COLLINS, COLO.

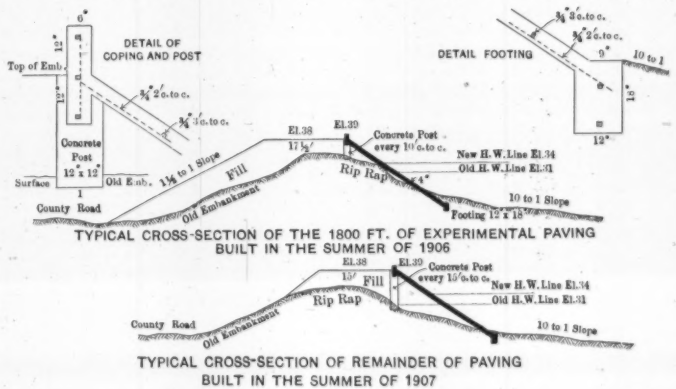


FIG. 4.

Before the improvement was made it had a capacity of 7 400 acre-ft. and covered about 500 acres. In spite of the heavy rip-rap, the wave action had eroded the banks so much that the reservoir had become a menace to the lives and property of the people living below it. There was about a mile of this embankment, varying from 16 to 25 ft. in height. Two typical cross-sections, showing the condition of the bank, are given in Fig. 4.

After considering several schemes for this work, it was decided, as an experiment, to put in 1 800 lin. ft. of reinforced concrete slope paving where the wave action was most severe. The bank was cut back below and filled out above high water to make a 1½ to 1 slope.

Mr. Houston. On this the paving was laid in sections 7 ft. in width, running from top to bottom.

During the following year, no serious crack having developed in this paving, the remaining embankment was covered. This new work, however, was laid entirely on fill with beams, 15 ft. from center to center, moulded in place in trenches cut in the bank to support it in case the earth settled away from it.

The cost of this paving was $1.68 per sq. yd., the cement costing $2.40 per barrel. It has proved very satisfactory, and four or five other reservoirs have adopted the same scheme.

Another type of structure is shown in Fig. 2, Plate I. It consists of a reinforced concrete ditch lining, outlet gates, sluiceway, and drop by which the waters in the Eaton Ditch are discharged into the Windsor Reservoir. This is located about 12 miles east of Fort Collins, Colo.

There are five gates, having 4 by 6 ft. clear opening, the sills being 3 ft. below the bottom of the ditch. The lining extends about 30 ft. up the ditch to prevent the scouring of the banks due to the increased velocity when the gates are opened. Above the gates, and under the platform from which they are operated, there are five overflow weirs, their crest being 6 in. above high-water line.

In case of a sudden rise in the ditch, the surplus water would discharge into the same sluiceway as the gates. The channel below the gates is gradually narrowed to a width of 9 ft. and a depth of 5 ft., and this extends 200 ft. to a 10-ft. drop. The water then discharges through an open cut into the reservoir. The side walls of this channel are supported against the earth pressure with 8 by 8-in. reinforced concrete struts. In all this work the Johnson bar was used as reinforcement.

Mr. Lyman. RICHARD R. LYMAN, ASSOC. AM. SOC. C. E. (by letter).—The writer has been impressed by the fact that some irrigation work, done for individuals and for private companies, is necessarily different, in at least two respects, from that shown and discussed by Mr. Newell. The first difference is in the cost, or quality of the work. Individuals and private companies cannot often afford to invest, in the storage and distribution systems they construct, the amount of money that the Government uses for similar structures. Then, in the second place, in many agricultural districts, the point at which the water is diverted is often located in soft earth, while all the structures shown by Mr. Newell were built in places where it was comparatively easy to reach bed-rock in the bottom of the stream from which water was to be diverted.

The writer has recently designed and constructed two dams in the channel of the Sevier River, near the central part of Utah, where the slope of the bed of the river is only about 3 ft. to the mile, and where

FIG. 1.—PLACING REINFORCEMENT AND PAVING ON TERRY LAKE EMBANKMENTS, FT. COLLINS, COLO.

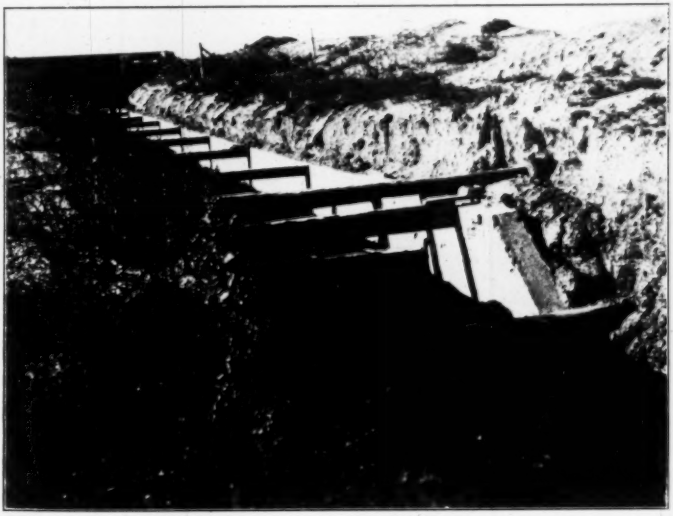


FIG. 2.—SLUICEWAY AND DROP BELOW GATES OF WINDSOR RESERVOIR.

the distance to bed-rock is unknown. Wells have been driven in this neighborhood to depths of several hundred feet, and in no case has a layer of rock been encountered. The earth through which these wells have been driven is made up of alternate layers of clay and sand, these layers varying in thickness from a few inches to a few feet. Mr. Lyman.

The writer is not presenting this matter with a view of dwelling upon the construction of the dams themselves, even though they have been constructed in this soft material, but it is his opinion that perhaps the construction of the concrete spillways over these dams may be of interest, since each must carry at times a flow of water amounting to about 2 500 cu. ft. per sec. and must deliver this water to the channel of soft earth below with a velocity such that the moving water will not disturb the surrounding earth so as to endanger either the dam or the spillway itself.

The first of these dams was designed and built for the Deseret Irrigation Company, of Hinckley, Utah, and the Irrigated Lands Company, of Salt Lake City, Utah.

It is in Millard County, about 2½ miles west of the new town of Burtner, on the line of the San Pedro, Los Angeles, and Salt Lake Railroad.

The writer submitted, for the consideration of the companies concerned, the design of a steel reinforced concrete spillway very different from that which has been constructed, and estimated its cost at $24 000. These figures might have been perfectly satisfactory for such a construction if the Government had been going to do the work, but not so when the money had to be furnished by the farmers of the neighborhood. Nor was any fault found with the design. In fact, the only part of the plan that was given any consideration was the estimated cost, and this appeared so high to those concerned that the plan was quickly rejected and a new and cheaper design demanded.

This new design, in conformity with which construction was finally begun, was estimated to cost $8 500. Such additions and changes in design were made, however, that the actual completed structure cost about $14 000.

It was perhaps the financial consideration thus thrust upon the writer which, during his rather careful consideration of this design, led him to construct the basin shown in cross-section at *A* in Fig. 6, a construction unlike anything of the sort that has come to his attention.

The curved chamber or basin at *B*, Fig. 6, into which the water falls after passing over the bulkhead at *C* (which is not shown in place) involves the same principle as does the chamber at *A*, that is, the water in it takes up the velocity, more or less, of that water which comes over the bulkhead, and thus decreases the shock upon the structure due to the falling water.

Mr. Lyman. The structure was completed in the fall of 1907, and since that time water has been running over it almost constantly.

When, with all the timbers removed, that compose the bulkhead, the water was running over the crest at *C* 4 ft. deep, the sheet assumed a uniform thickness of about 1 ft. on the long slope, and across the bottom to the vertical wall *D*, before the thickness changed. When the wall, *D*, was encountered (or the self-formed water-pad, *E*, perhaps), the stream went vertically into the air to a height of some 8 ft., and then fell virtually upon itself practically without horizontal velocity. The water then moved on down the stream almost without commotion.

It will be noted in the views on Plate II, as well as in the sketch, Fig. 6, that the velocity of the water in the basin, *A*, is just sufficient to keep the down-stream water from backing into the basin, and therefore it maintains the vertical wall of water shown. This spillway has six openings, each 16 ft. wide from center to center. The piers between the openings are each 18 in. thick, making the net width of the stream between the outside piers 87 ft.

This dam with its spillway was constructed in the bottom of a channel cut by a reservoir full of water in the spring of 1906. This water escaped from the reservoir after the washing out of an old wooden spillway which was located on the site where the new one has been built.

The second of these dams was built for the Melville Irrigation Company, 8 miles farther up the river. The dam is about 800 ft. long, and has a maximum height of 36 ft. above the bottom of the river. This work has also been done by the farmers of Millard County.

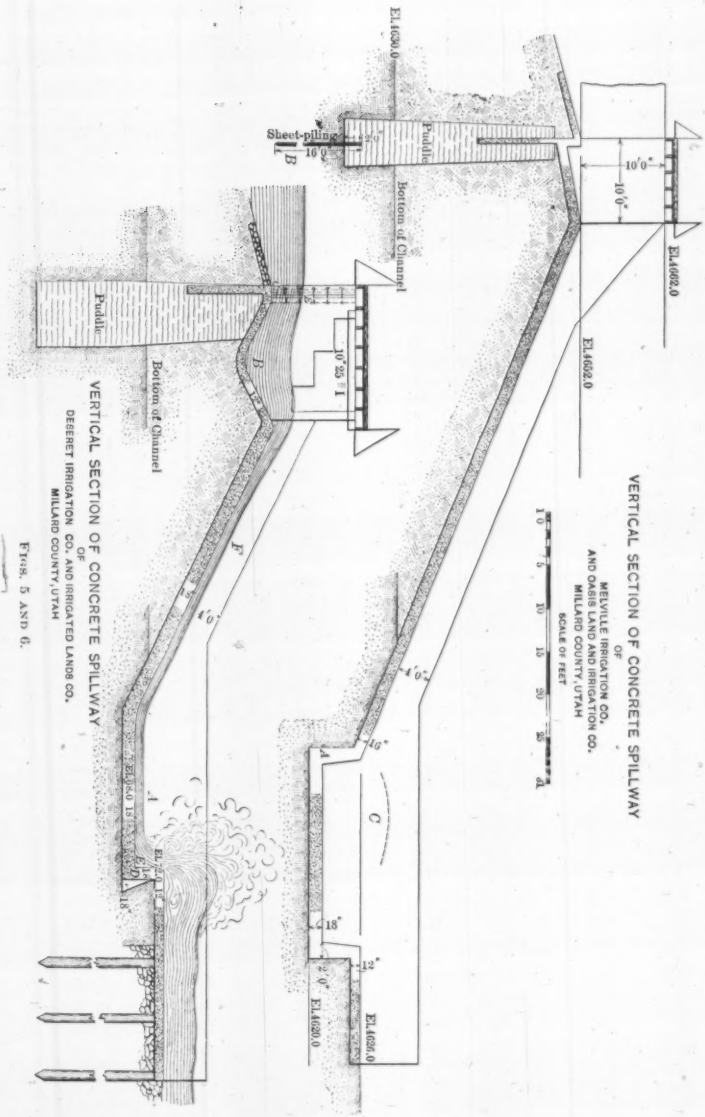
The land upon which this construction was made was poorer than that where the spillway and dam of the Deseret Irrigation Company was built, for the reason that the latter was clean clay, of comparatively good quality, which had been recently laid bare by flood waters, while the former was land in the bottom of the old river bed, which had been subjected to repeated freezing and thawing for an indefinite length of time, and had probably been shifted about more or less by the high waters of the river.

Borings were made to determine the nature of the ground on this site, and it was discovered that in some places the clay was within a few feet of the surface, while in others an excavation some 10 ft. deep and a boring 14 ft. farther were made before the clay was reached.

In order to tie the puddle core of the dam to this underlying clay, excavations were made, but where the depth to this clay was such that sufficiently deep excavations could not be made conveniently, sheet-piling was driven, for the purpose of uniting the core and the clay.

There was hardly any seepage through or under this dam, except in the river channel, where the presence of the river at one time, and

Mr. Lyman.



VERTICAL SECTION OF CONCRETE SPILLWAY
OF
MELVILLE IRRIGATION CO.
AND OASIS LAND AND IRRIGATION CO.
MILLARD COUNTY, UTAH
SCALE OF FEET
1 0 5 10 15 20 25 31

VERTICAL SECTION OF CONCRETE SPILLWAY
OF
DESERET IRRIGATION CO. AND IRRIGATED LANDS CO.
MILLARD COUNTY, UTAH

FIGS. 5 AND 6.

Mr. Lyman. the haste to get the fill up safely beyond the water surface at another, may have caused some imperfect work in taking the soundings and driving the piling. The seepage at this point, however, is not very great, and, since this slight flow is clean, it is doing little or no "cutting," and, therefore, will probably give no serious trouble.

A cross-section of the spillway over this dam is shown in Fig. 5.

The wall, *A*, is the principal feature of difference between this spillway and that previously considered. In Nature, where the velocity of a flowing stream is reduced, more or less, in a comparatively short time, the water makes a large or small basin, the size depending upon existing conditions; and this basin, filled with water, protects the surrounding material from further disturbance. It was in an effort to produce this same condition, in connection with these spillways, that led the writer to make the designs mentioned above.

In the first case, as shown by the views on Plate II, as well as in Fig. 6, the velocity acquired by the water as it runs down the slope, during the high-water periods, is such that it drives all but the moving water out of the basin; and it was to compel the water leaving the slope to enter a body of more or less quiet water that the wall, *A*, in Fig. 5, was introduced into the second construction.

Since, however, a tunnel or culvert of reinforced concrete extends through and under this second dam, it has not been found necessary, as yet, to discharge any great quantity of water over the spillway. Most of the water has gone through the tunnel; some, however, has been diverted into the canals, while only a small portion has gone over the spillway.

The tunnel is 8 ft. high and 4 ft. wide. It is built on a slight grade, and discharges, as shown in Fig. 7, into one end of the basin.

The effect of this basin filled with water upon the velocity of the water flowing through the tunnel is not all that could be wished. Since the basin is but 4½ ft. deep, while the depth of the tunnel is 8 ft., the bottoms of both being on the same level, the 3½ ft. of water flowing in the upper part of the tunnel (*C*, Fig. 7) goes directly over the lower wall of the basin as if no basin existed, while the lower 4½ ft. of water creates comparatively little commotion in the waters of the basin. Practically, the 4½ ft. of water is confined while the 3½ ft. is free; therefore, for this reason, perhaps, most of the water actully moves in the upper portion of the tunnel. If the cross-section of the tunnel had been changed from the 8 by 4 ft. gradually to, say, 4 by 10 ft., the 4 ft. being the height, all the water would have been discharged against the down-stream wall of the basin, and its velocity would probably have been reduced practically to zero before the flow down stream commenced. The net width of the spillway in this second case is also 87 ft.

This basin feature has also been used in the construction of all the

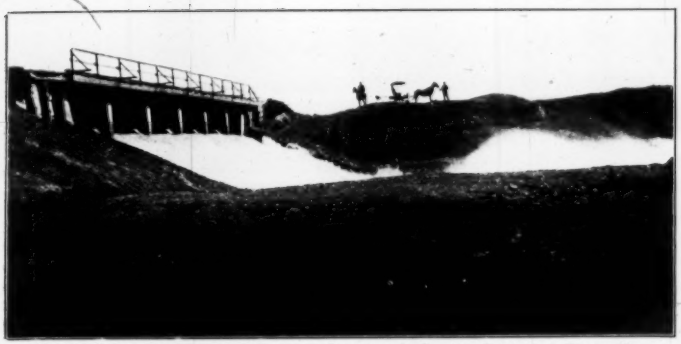


FIG. 1.—CONCRETE SPILLWAY, DESERET IRRIGATION CO. AND IRRIGATED LANDS CO., MILLARD COUNTY, UTAH.

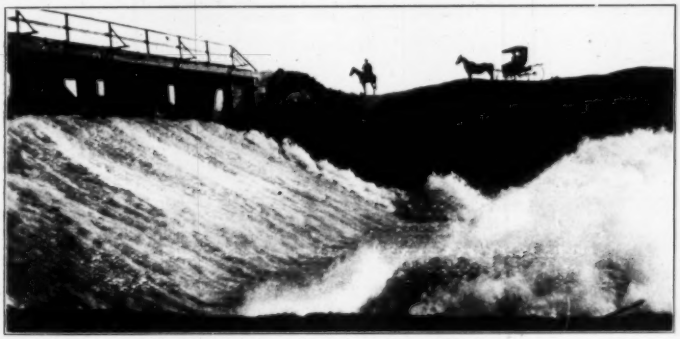


FIG. 2.—SPILLWAY CARRYING WATER 4 FT. DEEP.

FIG. 3.—VERTICAL WALL OF WATER AT DOWN-STREAM SIDE OF BASIN AT FOOT OF SPILLWAY.

head-gates, diverting devices, and "canal drops" of the Melville Irriga- Mr. Lyman.
tion Company, whether the construction has been of concrete or wood, and, although the canal system has been in operation but a few weeks, the results in this soft soil seem to be very satisfactory.

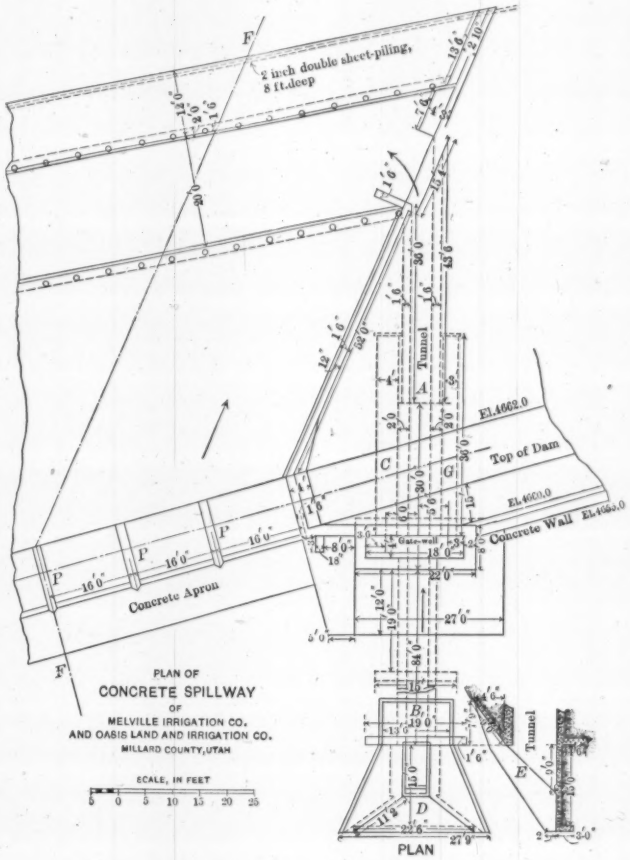


FIG. 7.

The plan of a portion of the Melville Spillway, Fig. 7, shows that the direction of the long slope, *F*, makes an angle of 38° with the piers, *P*, which are at right angles with the direction of the dam. This change in direction was made in order to divert the flowing water

Mr. Lyman. toward a railway bridge some few hundred feet below, instead of toward the large earthen fill at the end of the bridge.

The tunnel that extends through the dam is shown at *A*, Fig. 7. Its height above the apron over which the water flows when it leaves the spillway is shown by the curved line, *C*, in Fig. 5.

The reinforced concrete gate-well, *B*, Fig. 7, contains the 4 by 8-ft. gate in the tunnel, and two circular gates attached to steel pipes, *C* and *G*, 4 ft. and 3 ft. in diameter, respectively. To these pipes water-wheels for power purposes are to be attached.

The dam here considered is used only for diverting water. The reservoir necessarily constructed is of no value for storage purposes, as the water must always be held at approximately the same elevation. This, therefore, is one of the unusual cases where an irrigation project and a power-plant go well together.

One other feature connected with this construction—the provision for a temporary gate at the upper end of the tunnel—may be of interest. As shown in plan at *D*, and in section at *E*, Fig. 7, a plane surface, 6 in. wide, making an angle of 45° with the horizontal, surrounds the up-stream end of the tunnel, and this is used as a seat for a temporary wooden gate. The pressure on this wooden gate, while it is being put in place, can be regulated by opening or closing one of the gates in the tunnel.

By opening a hole 6 in. in diameter near the top of this temporary gate and closing the gates in the gate-well, the tunnel can be filled with water and the pressure on both sides of the temporary gate be equalized so that the temporary wooden gate, after being slightly moved, will float to the surface.

Mr. Davis. ARTHUR P. DAVIS, M. AM. SOC. C. E. (by letter).—The valuable studies made by Professor L. G. Carpenter and others have shown that in many cases a large proportion of the water applied for irrigation returns to the drainage lines below such lands.

In every case, however, this results from a careless and excessive application of the water in irrigation; if it were applied in an ideally perfect manner, only so much would be used as would supply the needs of the growing plants and the unavoidable evaporation from the soil.

There is a wide margin between this ideal condition and the condition where such an excessive amount is applied as to satisfy the plants and also to over-supply the potential evaporation to such an extent as to produce an appreciable return seepage.

Wherever valuable quantities of return waters are available, it is conclusive evidence of a wasteful use which, in the ultimate development of irrigation, cannot be tolerated, and will not be sustained by the Courts. The right to water for irrigation in all the arid States depends on beneficial use, and the Courts have consistently held that this means reasonably economical use and not waste.

Any water right dependent upon return seepage for its supply is precarious, and may at any time be cut off by voluntary or enforced economy on the part of the wasteful users above, if there is additional land on which they are permitted to use the water. Mr. Davis.

This excessive use of water is well-nigh universal, and its wastefulness is not its worst feature. The excess waters often reappear upon lower lands, and render them either alkaline or swampy, or both. Large areas of fertile lands have thus been ruined.

The tendency of improved irrigation, and also of the extension of irrigation development, is to greater and greater economy, which must eventually result in eliminating the factor of return seepage, or in reducing it to a negligible quantity. There are areas with an open subsoil of gravel where it is difficult to apply any water without losing some in the subsoil; but, even in such cases, the interests of the water user or of his competitors for water may eventually compel the abandonment of such lands or the application of such methods as will prevent excessive waste.

In considering the ultimate development of a large river system, such as the Rio Grande, it is undoubtedly wise to use a considerable proportion of the water in the upper reaches soon after it leaves the mountains and before it has had much opportunity to evaporate. As more tributaries reach the river, the additional water supply justifies other diversions lower down.

As development progresses, storage becomes necessary in order that the winter waters and the spring freshets may be held until needed, but, for irrigation purposes, such storage requires favorable natural reservoir sites, which are usually of rare occurrence. It will not be possible to find such sites on all the important tributaries of such a stream as the Rio Grande. In addition, there is a multitude of small tributaries, each insignificant in itself but aggregating a vast drainage area, which cannot be used except by storage on the lower part of the main stream.

To utilize entirely the water supply of a large basin with a varied climate, it is necessary, therefore, to have at least one large storage reservoir well down stream, and, to make such a reservoir financially feasible, sufficient water supply must be reserved for its use to justify its construction. Otherwise, a large percentage of the drainage from the basin must forever run to waste.

GEORGE G. ANDERSON, M. AM. SOC. C. E. (by letter).—It is very gratifying to the writer that his brief opening address has elicited much discussion on several features of great importance to the development of irrigation in the Western States at this time. Mr. Anderson.

The growing recognition of the importance of the engineer's position in relation to development, alike in public and private works, is largely an outgrowth of that process of evolution which it was the endeavor to outline. In the early primitive works, his function was

Mr. Anderson. merely that of a surveyor. In the larger works, he either did not take, or was not permitted to take, sufficient time to study the country to be reclaimed, with the consequence that, merely in the matter of location, the economic aspect was invariably lost, and, unfortunately, canals cannot be straightened out later, as can railroads, to save distance and gradient, when the settlement of the country warrants such betterments. In the matter of construction, as has been suggested, structures were originally, and almost of necessity, of a temporary character, by reason of the more or less speculative nature of the enterprises in those times.

To the credit of the engineers, it may be justly said that they were the earliest advocates of stability and permanency in construction. The gradual change from the temporary to the permanent began with the realization of the frequent repairs and reconstruction, and was earliest manifested, the writer believes, in the renewal of lateral headgates. These are now, invariably, and especially in the larger canals, of stone or concrete, culverts and steel gates. The old timber flume is gradually being replaced by siphon pipes either of wooden staves or concrete, mostly the latter, and numerous types of steel flumes have been introduced. The enhanced land values, following the introduction of the sugar beet, assuring larger and more certain returns for irrigation enterprises, stimulated the movement for structures of a more permanent character, and that has been aided materially by the example set by the Reclamation Service in the general type of construction adopted in the public works under its control, though the projectors of private enterprises, relatively limited in capital and restrained by the requirements of immediate return on investments, are not yet prepared to follow on the more ambitious lines, and are probably not prepared to admit the immediate necessity therefor.

Mr. Houston has submitted an example of development in character of construction, as applied to reservoir embankments, protecting the water slope against erosion by wind action.

Previously, rip-rap was considered all-sufficient. The defect in this method consisted largely in the failure to provide any foundation for the rip-rap. Usually, the rock was placed immediately upon the earthen face of the embankment, which became softened by the wave action, working through the rock interstices, and resulting in the telescoping or uneven settlement of the rip-rap. A substantial facing of gravel or small boulders, to some extent, overcomes this defect, and also protects the face of the embankment from burrowing animals.

The concrete face, as described by Mr. Houston, is thoroughly effective, and is being extensively adopted, as he says. There may be settlement and cracking if the facing is put in place before the earth composing the embankment has consolidated and settled—a contingency which was avoided in the cases he mentions, as the embankments

had been constructed for some years prior to the placing of the concrete. The slope of the inner face of the Terry Lake embankment, which he mentions, would appear to be too steep, and it is to be noted that, recently, the standard cross-section of reservoir embankments has been reversed, in order to lessen the area of the section of concrete; that is to say, where the standard slopes would be 3 to 1 inner face and 2 to 1 outer slope, the water face is given a slope of 2 to 1. Some recent concrete linings have been greatly reduced in thickness, in one case, in the writer's knowledge, to 3 in., with reinforcement of ordinary Page wire. As the reservoir created by this embankment is very wide, with long exposure, it will be interesting to watch the results in the concrete facing. Mr. Anderson.

On the same lines with the structure for the Windsor Reservoir are a number of drops on the canal system of the Great Plains Water Storage Company; and a number of concrete siphons and concrete linings have been used on the diversion canal from the Arkansas River, recently constructed by the Colorado Fuel and Iron Company.

Mr. Finkle has given some instances of the failure of concrete work in irrigation structures, under certain conditions. In the first case, the conclusion is that sulphuretted hydrogen affected the cement, and in the second, that carbon dioxide from decomposition and fermentation of vegetable matter in a swamp, in combination with the lime in the cement, produced carbonate of lime, destroying the cement. He also mentions the wooden-stave pipe of the Denver Union Water Company, laid in soil only slightly alkaline with chloride and sulphate of sodium, there being an absence of carbonate of sodium.

This leads, naturally, to the consideration of the action of these alkaline soils—containing the sulphates, carbonates, and chlorides—upon concrete structures, and incidentally, to Mr. Maignen's questions as to what constitutes alkali and what are its effects.

The Experiment Station of the State Agricultural College has made considerable investigation of these effects, and has published several bulletins on the subject by Professor William P. Headden, the Chemist of the College. Bulletin No. 132, "The Destruction of Concrete by Alkali," has recently been published, and in this Professor Headden treats of the disintegration, within eight or nine months after laying, of concrete tiling 16 or 18 in. thick. He found the point of attack to be either in the center of the cement mass or near the inner surface, and concludes that the decomposition is due to the action of the water, *i. e.*, of the salts held in solution. An analysis of two samples of the water acting on the tiling showed 1 252.6 gr. and 542.3 gr. total solids per Imperial gallon, respectively; in the former there were 493.5 gr. of sulphuric acid with an extremely large proportion of magnesia, in the latter, 42.31 gr. of magnesic oxide—7.8% of the total solids. He had examined numerous samples

Mr. Anderson.

of the waters from that district, presumably the Arkansas Valley, and found them "uniformily heavily laden with the sulfates of lime and soda with comparatively large quantities of magnesia," and uniformly some carbonate present.

He considers "the amount of chlorine or the corresponding chlorides not large and are probably subordinate elements in the alteration of the cement," and concludes that: "The action of the ground-waters seems to have been one of chemical change converting the lime of the cement into a sulfate and carbonate accompanied by the removal of silicic acid, alumina and lime and totally destroying the cohesiveness of the concrete."

Quite recently, the writer observed a concrete division gate in the Arkansas Valley, which was constructed less than two years ago. It had every appearance of being well built and of good proportions, but the apron, apparently 6 in. thick originally, was entirely honeycombed and could be pulverized in the hand. About half a mile from it was a reservoir embankment in which the apron of the outlet was similarly destroyed, exposing the reinforcement, which was in no way affected by the destructive element, and the exposed part of the outlet was showing similar rapid disintegration. The inner slope of the reservoir embankment was paved with reinforced concrete, and was apparently unaffected—the reservoir being full at the time of inspection, though it is probably rarely so.

The Bureau of Soils, of the U. S. Department of Agriculture, has devoted considerable effort to the investigation of the analysis of soils in the arid region, and to the analysis of waters applied in irrigation as well, and it is to be hoped and expected that their valuable work may be continued and extended.

Attention has also been directed to the drainage of tracts that have become over-irrigated and alkalied, examples of which may be found extensively in the Poudre Valley. Some individual efforts have been made, and successfully, in the drainage of such lands, but the writer is of the opinion that the best results can only be achieved by co-operative effort, in large districts, and on broad and comprehensive lines.

The feature of "return flow" or seepage waters has received considerable attention in the course of this discussion. It undoubtedly exists, in considerable volume in some streams under certain conditions, and in slight volume or not at all in others. It may be true that greater development has occurred in Colorado by the extension of irrigation ditches and canals from the heads of the streams outward to the plains than would have been possible, within the State limits, at any rate, and under the conditions which have prevailed, had the outlying plains area been the field of earliest reclamation. If the contention of Mr. A. P. Davis and others be correct, that the large volume of return flow is the direct result of wasteful methods in the applica-

tion of water for irrigation—and it cannot be denied that wasteful methods have existed and do exist—then the irrigable area has not been increased above what it ought to have been, but has merely been spread over a greater territory. It is doubtful if this return flow is increasing either actually or in proportion to the increase of the irrigated area, or if its amount is as great as asserted, by Mr. Fellows, for instance, in the statement that from one-third to one-half of the water applied to irrigation in the South Platte River returns to the stream, or by Professor Carpenter that "about 30% of the water applied in irrigation on the Poudre returned to the river." Mr. Anderson.

Return flow has been the subject of some investigation in Colorado in the past twenty years, and in view of its importance and the attention devoted to it in this discussion, the writer may be justified in entering into some detailed consideration of these investigations.

Beginning with 1885, on the Cache la Poudre, measurements have been made, usually in the fall of the year, to ascertain the amount of return flow, the existence of which, at least on that stream and on the South Platte River, was apparent to ordinary observation. In 1889, similar measurements were commenced on the South Platte, and later, the field of observation was extended to most of the tributary streams in the northern part of the State, to the Arkansas River, and still later, to the Uncompahgre, the Conejos, and the Rio Grande Rivers. Except on the South Platte, there have been occasional breaks in the continuity of these measurements. A record of them will be found in the 13th Biennial Report of the State Engineer of Colorado, 1905-1906.

In 1896, a report was prepared by Professor L. G. Carpenter on the measurements which had been made up to that time, and issued as Bulletin No. 33 of the Experiment Station of the State Agricultural College, in which will be found a description of the methods followed in making the observations. Professor Carpenter, subsequently, in the 10th and 11th Biennial Reports of the State Engineer, reviewed the results up to 1902, and it is understood, as therein stated, that another bulletin on the subject is in preparation by the Experiment Station.

In the Bulletin, certain conclusions are arrived at, and these are repeated in the 10th Biennial Report of the State Engineer, with the remark that they need but little modification. The later measurements clearly call for modification of these conclusions.

It is unfortunate that not only are these observations themselves of insufficient character, in that they are confined to only one day in each year, and that in the fall of the year, when the inflow is naturally the greatest—though on that point there is evidently divided opinion—but they are not accompanied by accurate and continuous data on such matters as the area of land irrigated in the districts tributary to the streams observed or the amount of water applied for irrigation each year.

Mr. Anderson. There is no doubt that the greatest return inflow occurs on the Poudre and South Platte Rivers; but in consideration of later measurements there is nothing to show either that the increase of such inflow is more as the irrigated area is greater, or that the increase is approximately proportional to the irrigated area. It would be profitable to make a detailed analysis of the measurements did space permit, but generalizations must suffice at present.

On the Poudre, an increase of 80% in the irrigated area in the past twelve years has yielded an increased inflow of 24%, while it now requires 1 282 acres to yield an inflow of 1 sec-ft. in place of 700 acres in 1896.

On the upper reaches of the South Platte, the return shows either an actual decrease or an increase below that due to the increase of irrigated area.

On the lower South Platte, the gain in return flow is also less than the gain in irrigated area, though it is still a high return.

On that stream the percentage is now and always has been greater than on any other stream in which the inflow has been observed; and it is strictly in accordance with actual conditions to say that there is now and always has been more wasteful use of water on that stream than elsewhere, in the northern section, at least.

In 1895, for instance, the amount used on 106 000 acres in the Poudre Valley was 260 000 acre-ft.,* which gives an average duty of 2.45 acre-ft. per acre.

In 1906, the two upper divisions on the South Platte used 377.741 acre-ft. on 109 474 acres or an average duty of 3.45 acre-ft. per acre.

That may be accounted for largely on one feature only—there has been less development of storage reservoirs on the Platte than on the Poudre; reliance is almost exclusively confined to the direct supply of the stream, always more or less inadequate, and when it is adequate, the water is used profusely to provide against the period of shortage certainly following. There is no doubt that reliance on stored water has most materially aided in securing a higher duty of water—in convincing the user that better results can be obtained from the application of moderate quantities of water.

There cannot be any doubt that much the larger percentage of return inflow is due to wasteful methods of irrigation, nor, from these later results, that it is decreasing—an evidence in itself of better methods which are likely to be continued and improved, as storage is developed and the consumer gains in appreciation of his own best interests.

And some of this inflow may be due to other causes than the application of water to the land for irrigation purposes.

* Bulletin No. 33, p. 40.

Mr. Anderson.

Mention is made of a canal near Greeley, where considerable damage was done by seepage immediately after its original construction. In 1895 this damage was renewed, apparently by the removal of the top layers of sand in the bed of the canal, in the process of cleaning and repairs, and in October of that year, apparently it was determined, by actual measurements, that there was a loss of 5.06 sec-ft. from an original volume of 25.86 sec-ft. in about 770 lin. ft. of the canal. That loss continues in large measure—at least, the damage by seepage on the adjoining land continues—necessitating drainage and suggesting the puddling or lining of the canal itself. Undoubtedly, the great loss is due to the presence of a subsoil of coarse gravel, permitting rapid percolation, and it appears there is a large area of such subsoil in the immediate vicinity.

In that area, the pumping station of the original Greeley Water Works was located. On the cessation of pumping after the installation of the new gravity system, the well-house filled up in an incredibly short period, almost before the pumps could be removed.

It is unquestionably true that there is greater inflow in the lower section of the South Platte River than in any other stream observed or measured; but it is doubtful if all of it should be attributed to irrigation operations, properly so-called.

Bulletin No. 33 gives some information that is very suggestive in that connection:

"A relatively large proportion of the irrigation is given to the bottom lands, which are used for hay. * * * The river overflows the bottoms many years, and did so in 1893, 1894 and 1895, and soaks them with water sometimes for a considerable period. More water is applied in the bottom irrigation than in the uplands. The practice of fall irrigation is very extensively followed. The river then having sufficient water, all the lands with few exceptions are soaked. We do not have measurements to show how much water is thus applied, but from what I observed, and from the conditions, the watering seems to be a very profuse one. This land receives more water than an equal area on the Poudre, and is, as a whole, much closer to the river. These conditions tend to give a more profuse and a speedier return to the Platte."

The conclusion is inevitable that, if the above conditions prevail at the time of the annual measurements, a large part of the water found in the stream is overflow, and not the return inflow of seepage waters.

In 1906, on Big Thompson River, the mean inflow, the highest recorded, 65.31 sec-ft., gives 1 sec-ft. from every 1 500 acres.

On Boulder Creek, the mean inflow, again the highest recorded, 39.4 sec-ft., gives 1 sec-ft. from every 1 862 acres.

On St. Vrain Creek, the mean inflow, 30.49 sec-ft., gives 1 sec-ft. from every 3 430 acres irrigated.

Mr. Anderson.

On Clear Creek, the average inflow of four measurements, 15.63 sec-ft., from 109 900 acres irrigated, gives 1 sec-ft. from each 7 031 acres, though considerable portions of the area irrigated drain directly to the South Platte River.

The Arkansas River has been treated in two sections, and has only been measured three times in an interval of ten years. The results on a stream of its magnitude, with the great territory tributary to it, are significant. In the lower section of 208 miles, the return inflow in 1897 was 331 sec-ft., in 1907 it was 250 sec-ft.

On the Rio Grande River, in the San Luis Valley, only three measurements have been made, and at considerable intervals. It is not possible to conclude from them that there is an increase on that stream. In 1900, there was a loss between Del Norte and Monte Vista, as stated by Mr. Follett, and also a small loss from the Conejos to the State Line, the former converted into a gain in later years, and the latter, in one year's observation only, barely maintaining the upstream gain.

It is concluded that the inflow is practically the same throughout the year, that it is more in summer and less in winter, principally because of the effect of the temperature on the soil. That conclusion will not readily be accepted. Ordinary observation indicates otherwise. Upon that, little reliance would be placed, against the clear evidence of continued observations. It does not seem reasonable to conclude that the result of the measurement of such inflow on one day in the year, and that in the fall, would determine or indicate the flow for the remainder of the year.

The few measurements made at other periods, while varying in proportionate amount, as would naturally be expected, strongly indicate that the reverse of the conclusion as stated above is really correct.

Of all the combined measurements, only twelve have been made in any season other than the fall, and, from these few individual summer measurements, it cannot be concluded that the inflow is greater in summer; on the whole, it seems to be much less, and that is in accordance with observation unaccompanied by measurement. Indeed, there would seem to be a period of inflow, extending from October throughout the winter months to the following March or April, in accordance with the natural conditions which would seem to affect their operation.

With the conclusion, in its general terms, that the passage of seepage waters through the soil is very slow, so that it may take years for the seepage from the outlying lands to reach the river, there will be ready agreement.

Mr. Follett has called attention to the investigations made by Professor Slichter on the Rio Grande River, and to other examinations for the U. S. Geological Survey, the results of which are embodied in Water Supply and Irrigation Papers Nos. 67 and 141, and

Mr. Follett has himself contributed valuable information on the subject.* Mr. Anderson.

And this well-known fact of the slow movement of seepage water may, to some extent, at least, account for the erratic and seemingly unresponsive volume of the inflow in relation to the amount of surface flow.

For instance, 1900 and 1905 were years of high surface flow in most of the streams in the northern section of the State, especially during April, May, and June, and, in such years, when the application of water would naturally be greater than normal, the return inflow would naturally be expected to show an increase. Such, however, is not the case, in these years; the inflow is either normal or below normal.

On the other hand, 1902 was a year of phenomenally low flow, and in all the streams of the northern section the return inflows were below—in some instances, greatly below—normal.

In Bulletin No. 33, it is concluded that "the amount of seepage is slowly but constantly increasing." The later measurements do not bear out that conclusion, except on the Poudre and South Platte Rivers, and on these only slightly, and not in proportion to the increase of the irrigation area.

It is further concluded that: "The seepage being nearly constant throughout the year, while the needs are greater in summer, the use of storage will best utilize the water from inflow."

It has already been pointed out that there are not sufficient data to warrant the conclusion of the constancy of the inflow, and that the evidence of the few measurements made outside of the fall of the year strongly indicates that the reverse is true. It is quite evident that the greatest return flow, proportionately and in fact, occurs on the South Platte River, and the following table of the mean surface flow of the stream at Denver and near the mouth of the Poudre River, for the past thirteen years, clearly indicates the period of return inflow:

Month.	At Denver.	At Poudre River.
January	124 sec-ft.	1 105 sec-ft.
February	141 " "	1 041 " "
March	186 " "	724 " "
April	473 " "	1 158 " "
May	1 090 " "	2 464 " "
June	956 " "	1 987 " "
July	467 " "	598 " "
August	397 " "	334 " "
September	248 " "	219 " "
October	198 " "	501 " "
November	204 " "	806 " "
December	159 " "	915 " "

*In a report embodied in Part 2, Senate Executive Document 41, Fifty-second Congress; and in an address, "The Underflow of the Great Plains," read before the Irrigation Congress held in Denver in 1894.

Mr. Anderson. The irrigation season extends from April to October, inclusive; the normal high-water season embraces April, May, and June. It is to be borne in mind that the flows at the Poudre River are the volumes in the stream after the demands for the up-stream irrigation have been supplied. It will be noted that in August and September only are the discharges of the down-stream station less than that of the up-stream, while the great increase in the flow at the down-stream station in the non-irrigation season, and also in the last irrigation month, October, is the strongest evidence that the great bulk of the return inflow occurs in these months.

By storage only can full advantage of this feature of the results of irrigation, whether avoidable or not, be realized, and it is extremely fortunate that the character of the country is such that it is possible to develop reservoirs in which to store these waters, and that they are rapidly being constructed in connection with some of the irrigation districts referred to in the opening discussion.

As Mr. Davis well points out, the water supply dependent upon return seepage is precarious, and may at any time be cut off by involuntary or enforced economy on the part of the wasteful users above. That such economy is gradually being voluntarily practiced above the lower reaches of the South Platte River, there is little room for doubt—the consumers are wise in extending reservoir development.

Coming finally to the conclusion that as much as 30%, or from one-third to one-half of the water applied in irrigation returns to the stream, there would be some surprise at the result were it not made plain, in Bulletin No. 33, that the assumption is made that the inflow shown on one day in the fall of each year is the inflow for every day in every year. Lacking more extended if not continuous measurements, that cannot be accepted as a correct assumption. If it were, it would be true that on the Poudre River in 1895, the return flow was 30% of the water applied in irrigation. But it would not be true in 1906, when the inflow had not greatly increased over that in 1895 while the irrigated area had doubled and there is no available information as to the amount of water applied.

If it were a correct assumption, then in 1905 the return inflow at the State Line on the South Platte River exceeded the water applied in irrigation in all the divisions of that stream and all its tributaries with the exception of the Poudre River.

There would not appear to be much room for doubt as to the cause of this return inflow. The water applied in irrigation, not actually absorbed by growing plants and by evaporation, fills the subsoil and gradually drains out into the streams. During the irrigation season of normally seven months, the sponge is being filled; in the remainder of the year it is being squeezed out. It can scarcely be hoped that the ideally perfect manner of applying water, mentioned by Mr. Davis,

will ever be reached; it can be approximated, however, as these later "seepage" measurements clearly indicate. It may also be concluded that the sponge does not demand the same quantity of supply, but it would seem to be most important to determine, if possible, the relative quantity of inflow at all seasons of the year, if for no other reason than to make accurate conclusions as to the real quantity of water to be depended on from this source, if it is to be depended on at all. That is merely an extension of the suggestion made by the writer in the opening discussion, that more liberal appropriations be made, by the Nation and by the States, for hydrographic observations, in order that these may be accurate and full. Mr. Anderson.

Mr. Davis correctly says: "The right to water for irrigation in all the arid States depends on beneficial use, and the Courts have consistently held that this means reasonably economical use and not waste."

Unfortunately, some of the Courts, in Colorado at least, recognize this return flow as a necessary consequence of irrigation, and, in a broad sense, seem to regard it as a beneficial use—led, perhaps, to that view by the belief that such return flow is of the relatively high proportion heretofore deduced. In applications for the transfer of water rights of early appropriations on the upper sections of streams to the lower sections, to which there seems to be general and well-founded objections in principle, there has recently crept in the recognition of this feature of return flow, and it has been argued, and, in some cases within the writer's knowledge, it has been decided, that the lavish use of water in the upper sections of the streams is beneficial in the sense of creating this return inflow. That has been the case in the Arkansas River, where the average duty of water has been 30 acres, in one instance 20 acres, per sec-ft., and where it would be difficult to demonstrate the return of one-tenth of the water applied.

It is too early to pronounce Government irrigation a success, as Mr. Means does. A few of the projects of the Reclamation Service have reached, and others are rapidly reaching, that critical stage in which only the element of success can be determined—the administrative period, the period in which the return of the capital invested must be secured, and the settlement of the lands tributary to the project accomplished.

It has always been and always will be a comparatively simple matter to expend money in irrigation enterprises, public and private, and always easier in public than in private ventures. It is another and much more difficult matter to secure the return of these expenditures, and that, after all, and under the terms of the Reclamation Act itself, is the true test of success. There are those who declare that the Government can afford to make these expenditures, without return, in order that these great areas of arid lands may be reclaimed and

Mr. Anderson. homes provided for countless thousands. The Reclamation Act, however, is not a philanthropic measure. As Mr. Means points out, "the irrigation homestead is not free; there are definite financial obligations to be met." The Act plainly provides that the charges which shall be made upon the entries on lands under the various projects "shall be determined with a view of returning to the reclamation fund (in annual installments, not exceeding ten) the estimated cost of construction of the project, and shall be apportioned equitably;" and estimated cost is doubtless intended to cover actual cost. It is further provided that the reclamation fund shall be used for the maintenance and operation of the various works constructed under the provisions of the Act, with the further provision that, when payments have been made for the major portion of the lands irrigated, the management and operation shall pass to the owners of the lands irrigated, and be maintained thereafter at their expense. It is again concluded that the cost of management and operation, prior to that time, must be refunded by the land-owners.

The essential difference between private and Government irrigation enterprises, in their purely commercial aspect, is at once apparent from the above statement. Provided that settlement follows upon the completion of construction and the settlers meet with financial success, the Government is assured in the return of all its capital expenditure, be that greater or less than originally estimated, alike in construction and in maintenance and operation charges. These become a fixed charge against the lands reclaimed, returnable in not to exceed ten years after entry. The Government dispenses with interest charges, which the private company could not well afford to do. The private companies, certainly those that did not arrange for contracts for the supply of water to the tributary lands prior to investment in construction, assumed a large element of risk, which, superficially, does not exist in the Government enterprises.

On the other hand, the Government enterprises incur expenditures proportionately greater than would have been deemed commercially practicable a decade ago, and which, even now, are, in some instances at least, higher than the cost of "water rights" in private enterprises, where all the conditions are otherwise equal. That may be justified by the enhanced value of irrigable land in the past ten years; by the introduction of more profitable crops, better adapted to irrigation conditions, and the gradual improvement in methods, in the economical use of water; in better systems of agriculture; and, to some extent, the presumed greater security under the canal systems of modern construction.

Withal, to secure the return of the capital invested in the Government enterprises is one of the many kinks of the problem Mr. Means refers to, and, under all the circumstances, will be followed with the keenest interest. When accomplished, and not until then, the success

of the undertakings can be declared, and it will not alone be gratifying to the advocates of the Reclamation Act, but will prove a stimulus to private enterprises, the sphere of whose operations is by no means circumscribed yet. Mr. Anderson.

That part of the problem, as Mr. Means writes, is largely a human one, and it ought to be a simpler problem in the future than it has been in the past, if, for no other reason, than that the settler on irrigated lands at this time has the benefit of the dearly-bought experience of his predecessors in that line of development, and the management can, equally well, profit by the failures and shortcomings of the men who devoted years of earnest effort before success was awarded them. It is true, as the writer has pointed out, that "a large number of the unfortunate ventures in irrigation enterprise have finally developed into successful undertakings," but it does not necessarily follow, and, as a matter of fact, in the majority of cases, it is not correct to say, as Mr. Means does, that the fault was largely that of the original promoter or manager, who certainly did not have "the same opportunities for success as the man who finally succeeded."

These early efforts were simply ahead of their time in the course of development, and they failed largely for want of the proper methods, the proper conditions underlying farming by irrigation, and the difficulty of securing settlers, not only of the right type, but with even the smallest knowledge and appreciation of the elemental principles of farming by irrigation. That the Government must accept the water-right application of any man who has the money for a first payment, does not place it in any worse position than the private companies who certainly could not and even now cannot very well afford to reject the application of any man offering money. The private company who had or has a selection of settlers is in the nature of a *rara avis*—more frequently they had to search the highways and byways of the older communities, and labor with the straggler to convince him of the advantages of irrigation farming.

To secure settlement is the crux of the irrigation problem. It may be more difficult in these latter days for the reason that the intending farmer under irrigation is better equipped than formerly; he has more adequate knowledge of the requirements in all respects; he has keener appreciation of the real value of water; he is, as a rule, a better business man, and is possessed, or believes himself to be possessed, of ability to manage the irrigation works that contribute so largely to his individual failure or success; in other words, the advantages of the canal system in all its ramifications, equipment, and management, under which he will elect to stake his fortune and his future, must be convincingly apparent to him as a commercial proposition.

To Government ownership and management of the streams in the arid region there is strong and growing opposition.

At the Fifteenth National Irrigation Congress, which met at Sacra-

Mr. Anderson. mento in 1907, the report of a "Committee on Interstate Water Rights" was submitted, in which, among other things, this question was considered. The Committee had canvassed the opinion of forty-seven representative men, leading lawyers, engineers, and men skilled in the use of water for irrigation in all parts of the United States, to whom had been submitted interrogatories on that and similar questions, twenty-eight expressed themselves in favor of absolute State control of the water within the borders of the State, whether flowing in interstate or local streams, thirteen in favor of Government control and two in favor of divided control.

That result is indicative of the prevailing sentiment on the question and of the conclusion that, with many defects yet to be corrected, State control, as expressive of the desires of the actual user of water, has given and will continue to give satisfaction to the people. It is entirely in line with the conclusion which must be irresistible to those who have watched and have been closely identified with the development of irrigation in the last generation, that the consumer of water himself is fully alive to the real requirements of the situation and is best fitted for the management of all that pertains to its welfare and progress.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1093

CURVE RESISTANCE IN WATER PIPES.

By Ernest W. Schoder, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. George Jacob Davis, Jr., and Ernest W. Schoder.

The object of this paper is to present the results of some measurements which seem to throw new light on a subject that awakened considerable interest and discussion among the members of this Society some seven years ago.

A. V. Saph, Assoc. M. Am. Soc. C. E., and the writer, in their discussion of the paper* by Messrs. Williams, Hubbell and Fenkell, presented results of experimental studies on the flow of water in a line of 2-in. brass pipe with 180° curves, or return bends, of varying radii of curvature. It seemed difficult to harmonize these results† with one of the principal conclusions in the paper, namely:

"That curves of short radius, down to a limit of about 2½ diameters, offer less resistance to the flow of water than do those of longer radius."‡

In their closing discussion, this conclusion is further defined by Messrs. Williams, Hubbell and Fenkell in these words:§

"In a given length of pipe consisting of two tangents joined by a curve of 90°, the loss of head will decrease as the radius of the curve

* *Transactions*, Am. Soc. C. E., Vol. XLVII, "Experiments at Detroit, Mich., on the Effect of Curvature upon the Flow of Water in Pipes."

† Pages 319-322 of same.

‡ Page 191 of same.

§ Page 348 of same.

is decreased, to a limit of about 2½ diameters, and will increase as the radius is increased above that limit, the total length remaining the same."

Also:

"* * * for the range of these experiments, at least: To unite two points on two tangents intersecting at 90°, and equally distant from their intersection, by a pipe line consisting of portions of the two tangents and a curve of 90°, the line of least hydraulic resistance will be one in which a curve of about 2½ diameters radius is used."

At the time, no critical comparison was made between the results of the loss-of-head measurements on 180° 2-in. brass pipe curves and those on 90° curves in 12-in., 16-in., and 30-in. cast-iron water mains. This seemed hardly justifiable, with the limited data available. However, Mr. Saph and the writer did point out* the probability of large piezometric errors involved in the Detroit Experiments.

On this account, and because of other unsatisfactory features to be mentioned later, the writer felt the desirability of making further experiments in an attempt to clear up the situation. He is now able to present some new evidence that tends to limit the general application of the results of the Detroit Experiments, if it does not essentially contradict them.

The chief experimental problem that the writer set for himself was to find the losses of head due to each of a number of 90° curves of different radii, for as great a range of velocities as the available facilities would permit. Given two long runs of straight pipe connected by a 90° curve, one part of the problem is to measure the loss of head in a portion of the pipe line including the curve. The portion must be long enough so that the full effects on the flow of the water due to the curve are realized in the down-stream straight run of pipe. Another part of the problem is to find the loss of head in the same straight pipe used with the curves when it is uninfluenced by effects of curvature (or other disturbance) and when it is in the same condition as when used with the curves. This last is a difficult matter in any case with pipes of large size, as will appear presently. Evidence will be given to show, also, that it is often practically impossible, where the pipe lines are fixed in place underground.

The straight pipe chosen for the experiments first to be described

* *Transactions*, Am. Soc. C. E., Vol. XLVII, 1902, pages 317-321.

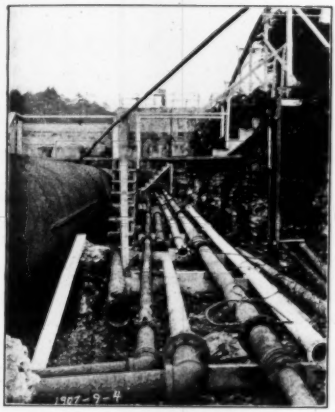


FIG. 1.—SIX-INCH PIPE LINE (AT THE RIGHT) AS SET UP FOR FIRST STRAIGHT-PIPE EXPERIMENTS.

FIG. 2.—CORNELL UNIVERSITY HYDRO-ELECTRIC POWER PLANT, AND 6-IN. PIPE LINE FOR CURVE EXPERIMENTS.

FIG. 3.—NOZZLE AT END OF 6-IN. PIPE LINE.

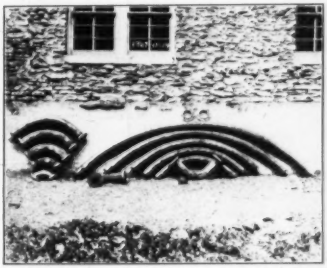


FIG. 4.—SIX-INCH, 90° CURVES, NOS. 1 TO 12.

was 6-in. wrought iron. Before the curve experiments were made, a straight line composed of six pipe lengths was set up in the pipe alley alongside the large canal of the Cornell University Hydraulic Laboratory. The pipes were flange-connected. The total length of 6-in. pipe was 122 ft. The loss of head was measured in a length of 99.33 ft., a length of 20.04 ft. being allowed up stream from the first piezometer for the disturbances due to entry from a 12-in. header to die down. The piezometers consisted each of two diametrically opposite holes in the pipe wall into which $\frac{1}{8}$-in. T-handle cocks were screwed. A three-way connection served to join the short hoses from these cocks and the single long hose to the gauge. A water differential gauge was used to measure the loss of head. A calibrated concrete measuring tank, of 500 cu. ft. capacity, received the discharged water from a 4-in. pipe with a 4-in. regulating valve through which the 6-in. line discharged. An instantaneous diverter deflected the discharge into the tank or allowed it to run to waste, as desired. The measurements lasted from 5 to 10 min., the time being accurately taken. Fig. 1, Plate III, is a photograph showing the pipe line. The results of these measurements are given in Table 2, where data from later straight-pipe experiments are given also.

After this the pipes were marked, disconnected, and transported to the bottom of the Fall Creek Gorge, in Ithaca, near the hydroelectric plant of Cornell University. Here the curve experiments were performed. Fig. 2, Plate III, is a photograph of this plant, and Fig. 1 is a plan of the pipe line.

The pipes composing the experimental portion of the line were the same, and were set up in the same order as when tested as a straight pipe line. The curves were placed between Pipes Nos. 1 and 2, the two up-stream pipes in the experiments described above, and as shown by Fig. 1. The down-stream tangent portion thus consisted of Pipes Nos. 2, 3, 4, and 5. Pipe No. 6 was not used for the curve experiments because this would have brought the end of the pipe line out into the creek.

At the discharge end of Pipe No. 5 there was attached a brass nozzle for measuring the velocity in the pipe line. This nozzle is shown by Fig. 3, Plate III. It had been calibrated previously by tank measurements in the Hydraulic Laboratory. The average discharge coefficient from 40 experiments, with pressure heads at the

base of the nozzle ranging from 1.649 to 50.208 ft., was found to be 0.988.

The lengths of the pipes, from face to face of flanges, are given in Fig. 1; the following are the inside diameters—the means of four measurements, two at each end:

Pipe No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
6.106 in.	6.086 in.	6.102 in.	6.078 in.	6.072 in.	6.083 in.

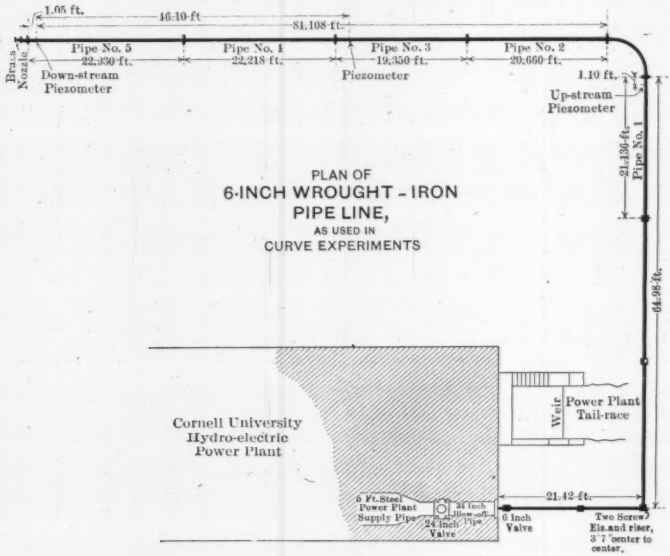


FIG. 1.

The Curves.—The curves used were made to order, except that Nos. 10 and 12, respectively, were standard "long sweep" and "short turn" 6-in., cast-iron, flanged, 90° elbows. Curves Nos. 1 to 6, inclusive, were bent from 6-in. wrought-iron pipe. Curves Nos. 7 to 12, inclusive, were of cast iron. All were 90° curves; and all were left uncoated.

The wrought-iron pipe curves had about 6 in. of straight pipe at each end. The ends had been threaded to receive standard flanges. The cast-iron curves were flanged, faced, and drilled complete, ready

for setting up. Fig. 4, Plate III, is a photograph of the curves stacked against the power-plant wall.

TABLE 1.—DIMENSIONS OF CURVES.

No. of curve.	Material.	Radius, in feet.	Radius, in pipe diameters.	A, in feet.	B, in feet.	$A + B$, in feet.	Length on center line, in feet.	Diameter, mean of four end calliperings.
1	Wrought iron.	10.00	20	10.54	10.52	21.06	16.77	6.09 in.
2	" "	7.50	15	8.04	8.02	16.06	12.84	6.18 "
3	" "	5.00	10	5.59	5.57	11.16	9.01	6.16 "
4	" "	4.00	8	4.54	4.52	9.06	7.34	6.11 "
5	" "	3.00	6	3.60	3.58	7.18	5.89	6.11 "
6	" "	2.50	5	3.05	3.10	6.15	5.08	6.09 "
7	Cast iron.	2.00	4	2.25	2.25	4.50	3.64	5.91 "
8	" "	1.50	3	1.75	1.75	3.50	2.86	5.95 "
9	" "	1.08	2.16	1.50	1.50	3.00	2.54	5.91 "
10	" "	0.95	1.90	1.08	1.08	2.16	1.75	5.91 "
11	" "	0.88	1.76	2.00	2.00	4.00	3.62	5.95 "
12	" "	0.67	1.34	0.67	0.67	1.34	1.05	5.93 "

The dimensions of the curves are given in Table 1, in which reference is made to the dimensions indicated in Fig. 2. The dimensions

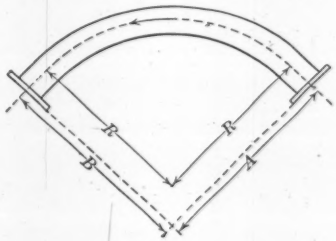


FIG. 2.

in Table 1 are for the curves as placed in the pipe line, the wrought-iron bends having screw flanges attached. The distances from the faces of the flanges to the ends of the wrought-iron curves were as follows: Curves Nos. 1, 2, 3, and 4, up-stream end, $\frac{1}{4}$ in., down-stream end, $\frac{15}{32}$ in.; Curve No. 5, up-stream end, $\frac{1}{2}$ in., down-stream end, $\frac{3}{4}$ in.; Curve No. 6, up-stream end, 1 in., down-stream end, $\frac{5}{8}$ in. The inside diameters of Curve No. 6 were measured also at points $22\frac{1}{2}°$, 45° and $67\frac{1}{2}°$ from the up-stream end. At these points, $\frac{1}{4}$-in. taps for the insertion of a Pitot tube had been made on both the vertical and hori-

zontal diameters. The measurements were as follows: at 22½°, 5.92 and 6.09 in.; at 45°, 6.08 and 6.08 in.; at 67½°, 5.95 and 6.15 in.

Curves Nos. 9 and 11 were made in error, the foundry making curves of quite short radius, with straight portions at each end, so that the dimensions from the center to the face were 18 and 24 in., respectively, where the writer's order called for curves with the same radii as the center-to-face dimensions. Curves Nos. 7 and 8 were made later, to correct this error.

The experimental pipe line was arranged with the idea of keeping all conditions the same except for the introduction of the several curves. Consequently, the flange joints in the portion down stream from the curves were not disturbed throughout the experiments. The entire length of 85 ft. of 6-in. wrought-iron pipe, together with the nozzle, was shifted bodily when a new curve was placed in the line. This was rather vigorous exercise for two men, but it was accomplished by a judicious tilting of the wooden horses supporting that part of the pipe line. The portion up stream from the curves was left unchanged during the experiments.

The same up-stream piezometer was used for the curve experiments as for the first straight-pipe experiments. The down-stream piezometer was a new one, of the same type, placed 1.05 ft. up stream from the down-stream end of Pipe No. 5 which adjoined the nozzle. A similar intermediate piezometer was placed 2.00 ft. up stream from the down-stream end of Pipe No. 3.

At first it was assumed that some effect of the curves might extend 100 or more diameters down stream in the straight pipe beyond.* The losses of head in all the curve experiments were measured between the piezometer just up stream from the curves and the piezometer just up stream from the nozzle, distant 168 diameters down stream from the curves. These two piezometers were connected to the two branches of a differential **U**-tube mercury gauge by lines of ⅜-in. or ½-in. three-ply rubber tubing. The nozzle piezometer was connected to one branch of an 8-ft. mercury **U**-tube gauge, the other branch of which was open to the atmosphere. These gauges were provided with blow-off cocks for the removal of air from the gauge and connections.

In experimenting, the 6-in. valve was first opened wide to establish a swift flow through the pipe line. The gauge hoses connected to the

* *Transactions*, Am. Soc. C. E., Vol. XLVII, 1902, p. 302.

piezometers were allowed to run for a while before connecting them to the gauges, being pinched near the gauge end while connecting up. Finally, the pet-cocks were opened, and all traces of air were blown off. Then the gauge readings were recorded and checked. The 6-in. valve was then closed a little, and the readings were taken again as soon as the flow had become settled. In this way ten or twelve runs were made, the last being generally a repetition of the first run with the valve wide open. If there was time, a new curve was then placed in the line. Otherwise, the change was deferred until another day, in which case one or more check runs were made at the high velocities before removing the curve and substituting another. For each set-up, the level of the center of the nozzle with reference to the nozzle mercury gauge scale was determined. The alignment of the down-stream tangent was corrected after each change of curves.

When the work on the twelve curves had been finished, Curve No. 6 was replaced in the line to find whether or not any appreciable change in the condition of the pipes had occurred during the experiments. Then a number of Pitot-tube studies were made to determine the conditions of flow at the piezometers and in the curve. Later, a 6-in. screw elbow, of the ordinary steam-fitting type, was placed in the line, and a series of measurements made on it as for the other curves. Finally, the loss of head was measured in the portion (46.10 ft. long) of the experimental section farthest down stream, Pitot tube traverses having shown normal flow in the pipe 38 ft., or 76 diameters, down stream from the curves. Hence, this portion represented straight pipe unaffected by curvature effects.

The results of these loss-of-head measurements are given in Table 2. For simplicity, there is given only the mean velocity in the pipe line as deduced from the nozzle mercury pressure-gauge indications. The differential mercury gauge differences are taken directly from the checked subtractions in the field notebook. These differences, multiplied by 12.57, would give the loss of head, in feet of water, the specific gravity of mercury being taken as 13.57.

To illustrate the calculations involved in obtaining the velocity in the pipe line from the observations in the mercury pressure gauge the following is a sample:

In Experiment No. 1, Curve No. 1, October 10th, 1907, the gauge readings were: left 0.270, right 7.900. The difference is 7.630 ft.

The center of the nozzle-tip level was at 1.81 on the gauge scale. Hence the top of the left mercury column was 1.54 ft. below the center of the nozzle tip. The pressure head at the base of the nozzle, therefore, was $7.630 \times 13.57 - 1.54 = 102.1$ ft. The diameter of the nozzle tip was 2.738 in., and the diameter of the nozzle base was 6.123 in., the ratio of areas being 1 : 5. Theoretically, the nozzle-tip velocity is $C \sqrt{\frac{1}{1 - \left(\frac{1}{5}\right)^2}} \sqrt{2gh} = C \times 8.19 \sqrt{h}$, where h is the pressure head at the nozzle base. As stated above, the coefficient, C, for this nozzle had been found to be 0.988 by experiment. The mean diameter of the pipe line is 6.084 in. Therefore the mean velocity in the experimental portion of the pipe line was:

$$V = 0.988 \times 8.19 \times \left(\frac{2.738}{6.084}\right)^2 \sqrt{h} = 1.639 \sqrt{h}.$$

This gives, for this experiment,

$$V = 1.639 \times \sqrt{102.1} = 16.56 \text{ ft. per sec.}$$

The results given in Table 2 were plotted logarithmically on 10-in. base paper. Plate IV shows these plottings assembled.

Now, in order to study the effects of the curves, it is necessary to select a uniform basis of comparison. Thus the experiments were made by introducing the various curves between two fixed lengths of pipe. For this case, the observed losses of head may be compared with each other at once by using Table 2 or Plate IV; but such a basis takes no account of the comparative lengths of the several pipe lines, nor does it consider whether or not the same two points are joined by the combinations of straight pipes and curves.

The writer has chosen two bases of comparison. In one, all cases are reduced to equal lengths on the center lines of straight pipes and curves. In the other, all cases are reduced to what they would be if two fixed points had been connected by two straight pipe lines with the various 90° curves between them.

For both these cases it is necessary to know the loss of head in the straight pipe when it is unaffected by curvature. Two series of experiments already described give this information.

Turning to Plate IV, it is seen that the results of the first straight-pipe experiments do not agree with the later ones. Each series gives a good straight line, but the two lines have different slopes

TABLE 2.

Date, 1907.	Number of Experiment.	Observed differential mercury-gauge difference, in feet.	Velocity in pipe, in feet per second.	Temperature of water, in degrees, Fahrenheit.
	Curve No. 1.			
Oct. 10..	1	1.155	16.56	49
	2	1.085	16.00	
	3	0.990	15.27	
	4	0.772	13.41	
	5	0.708	12.81	
	6	0.625	12.06	
	7	0.380	9.29	
	8	0.285	7.96	
	9	0.198	6.59	
	10	0.118	4.93	
	11	0.055	3.46	
	12	1.158	16.58	
Oct. 12..	13	1.169	16.58	47
	14	1.104	16.10	
	15	0.956	14.95	
	16	0.858	14.13	
	17	0.756	13.24	
	18	0.680	12.53	
	19	0.590	11.64	
	20	0.436	9.96	
	21	0.308	8.20	
	22	0.187	6.38	
	23	0.074	3.82	
	24	0.034	2.67	
	Curve No. 2.			
Oct. 12..	1	1.097	16.65	47
	2	1.019	16.04	
	3	0.718	13.35	
	4	0.859	14.73	
	5	0.549	11.55	
	6	0.460	10.62	
	7	0.350	9.18	
	8	0.196	6.76	
	9	0.107	5.02	
	10	0.048	3.29	
	11	0.036	2.81	
	12	1.096	16.65	

Date, 1907.	Number of Experiment.	Observed differential mercury-gauge difference, in feet.	Velocity in pipe, in feet per second.	Temperature of water, in degrees, Fahrenheit.
	Curve No. 3.			
Oct. 12..	1	1.065	16.66	48
	2	0.994	16.11	
	3	0.859	14.95	
	4	0.770	14.05	
	5	0.682	13.28	
	6	0.600	12.39	
	7	0.488	11.09	
	8	0.318	8.85	
	9	0.242	7.69	
	10	0.110	4.99	
	11	0.051	3.45	
	12	1.065	16.66	
Oct. 14..	13	1.062	16.65	46
	14	1.005	16.16	
	15	0.892	15.18	
	16	0.750	13.91	
	Curve No. 4.			
Oct. 14..	1	1.071	16.62	46
	2	1.034	16.30	
	3	0.824	14.59	
	4	0.682	13.15	
	5	0.572	12.01	
	6	0.349	9.29	
	7	0.158	6.10	
	8	0.062	3.87	
	9	0.438	10.46	
	10	1.070	16.63	
Oct. 15..	11	1.070	16.63	45
	12	1.024	16.27	
	13	0.732	13.67	

TABLE 2 (*Continued*).

Date, 1907.	Number of Experiment.	Observed differential mercury-gauge difference, in feet.	Velocity in pipe, in feet per second.	Temperature of water, in degrees, Fahrenheit.
	CURVE No. 5.			
Oct. 15..	1	1.053	16.63	45
	2	0.985	16.09	
	3	0.762	14.05	
	4	0.642	12.85	
	5	0.460	10.80	
	6	0.240	7.63	
	7	0.100	4.86	
	8	0.048	3.42	
	9	1.052	16.63	
Oct. 17..	10	1.045	16.61	
	CURVE No. 6.			
Oct. 17..	1	1.036	16.65	47½
	2	1.004	16.40	
	3	0.893	15.41	
	4	0.644	13.04	
	5	0.298	8.67	
	6	0.410	10.36	
	7	0.238	7.78	
	8	0.121	5.53	
	9	0.046	3.41	
	10	1.028	16.61	
Oct. 19..	11	1.026	16.60	
Oct. 26..	12	1.034	16.61	42
	13	1.015	16.45	
	14	0.963	16.01	
	CURVE No. 7.			
Oct. 19..	1	1.024	16.61	47½
	2	0.819	14.80	
	3	0.631	12.90	
	4	0.544	11.94	
	5	0.287	8.58	
	6	0.212	7.31	
	7	0.123	5.62	
	8	0.076	4.38	
	9	0.039	3.20	
	10	1.025	16.62	

Date, 1907.	Number of Experiment.	Observed differential mercury-gauge difference, in feet.	Velocity in pipe, in feet per second.	Temperature of water, in degrees, Fahrenheit.
	CURVE No. 8.			
Oct. 21..	1	1.008	16.60	43
	2	0.858	15.26	
	3	0.782	14.50	
	4	0.694	13.64	
	5	0.331	9.26	
	6	0.419	10.50	
	7	0.172	6.56	
	8	0.100	4.99	
	9	0.050	3.44	
	10	1.016	16.62	
	CURVE No. 9.			
Oct. 22..	1	1.020	16.63	42
	2	0.981	16.40	
	3	0.881	15.40	
	4	0.780	14.00	
	5	0.426	10.55	
	6	0.230	7.58	
	7	0.107	5.15	
	8	0.041	3.13	
	9	1.020	16.63	
	CURVE No. 10.			
Oct. 22..	1	1.016	16.63	42
	2	0.990	16.40	
	3	0.905	15.65	
	4	0.778	14.48	
	5	0.595	12.60	
	6	0.324	9.26	
	7	0.288	8.70	
	8	0.214	7.41	
	9	0.126	5.60	
	10	0.064	3.97	
	11	0.024	2.46	
	12	1.016	16.64	
Oct. 24..	13	1.013	16.66	

TABLE 2 (*Continued*).

Date, 1907.	Number of Experiment.	Observed differential mercury-gauge difference, in feet.	Velocity in pipe, in feet per second.	Temperature of water, in degrees, Fahrenheit.
	CURVE No. 11.			
Oct. 19..	1	1.050	16.59	47½
	2	0.926	15.53	
	3	0.607	12.40	
	4	0.320	8.99	
	5	0.275	8.41	
	6	0.241	7.75	
	7	0.202	7.07	
	8	0.120	5.41	
	9	0.056	3.78	
	10	0.032	2.87	
	11	1.046	16.56	
Oct. 21..	12	1.052	16.58	43
	13	0.715	13.60	
	CURVE No. 12.			
Oct. 24..	1	1.046	16.62	43
	2	1.009	16.31	
	3	0.818	14.65	
	4	0.558	12.01	
	5	0.320	8.92	
	6	0.168	6.43	
	7	0.072	4.21	
	8	0.027	2.74	
	9	0.612	12.61	
	10	1.046	16.61	
	SCREW ELBOW.			
Nov. 12..	1	1.090	16.55	37
	2	1.036	16.15	
Nov. 18..	3	1.098	16.55	33
	4	1.053	16.21	
	5	0.912	15.02	
	6	0.682	12.94	
	7	0.515	11.20	
	8	0.331	8.92	
	9	0.174	6.40	
	10	0.071	4.04	
	11	1.088	16.55	

Date, 1907.	Number of Experiment.	Observed loss of head in 99.39 ft. of pipe, in feet of water.	Corresponding differential mercury-gauge difference for 46.10 ft. of pipe.	Velocity in pipe, in feet per second.
	STRAIGHT-PIPE EXPERIMENTS.			
First Series: Temperature of water: 68° at beginning, 70° at end.				
Sept. 4..	1	1.901	0.0701	6.03
	2	1.687	0.0622	5.67
	3	1.449	0.0535	5.22
	4	1.241	0.0458	4.80
	5	1.000	0.0369	4.29
	6	0.831	0.0307	3.88
	7	0.704	0.0260	3.55
	8	0.473	0.0175	2.87
	9	0.307	0.0114	2.27
	10	0.160	0.0059	1.61

Second Series*: Temperature of water, 33° fahr.

		Corresponding values.	Observed values.	
Nov. 18..	1	13.70	0.506	16.56
	2	13.19	0.487	16.23
	3	10.24	0.378	14.29
	4	6.83	0.2525	11.56
	5	4.40	0.1625	9.26
	6	2.45	0.0905	6.93

*The velocities for the second series are computed for the mean diameter of the experimental section (46.10 ft. long) which was 6.075 in.

and represent different laws of flow. The equations of these lines, reduced so as to represent loss of head in feet of water per foot length of pipe, are

For the first series, $H = 0.000\,669\ V^{1.87}$

For the later series, $H = 0.000\,598\ V^{1.94}$

To show more clearly the magnitude of this difference, the following calculated values are given:

	Loss of head, in feet of water per foot of length:			
	$V = 3$ ft. per sec.	$V = 5$ ft. per sec.	$V = 10$ ft. per sec.	$V = 16$ ft. per sec.
First series	0.0052	0.0135	0.049	0.119
Later series	0.0050	0.0135	0.052	0.129

Thus, at the outset, comes the question which must arise in all experiments of this kind: What was the law of flow of the identical straight pipe used with the curves when unaffected by curvature, but otherwise in the same condition? On this depends the calculation of the excess loss of head caused by the curves.

There are a number of possible causes for the difference shown above:

1.—The pipe may have become rougher by rusting in the interval between the two series of experiments;

2.—Pipes Nos. 4 and 5 together may have had different hydraulic properties from Pipes Nos. 2, 3, 4, and 5 together;

3.—The different temperatures of the water may have caused a difference in loss of head.

It was intended originally to bring the straight pipes back to the hydraulic laboratory and again test them as at first for loss of head after the curve experiments had been finished, but the lateness of the season prevented this.

Later in this paper the above possible causes of differences will be discussed more fully. In order to remove any question as to mistaken judgment, the results are worked up in both ways.

The individual observations, directly, are not used in the final comparisons. From the mean lines drawn on the logarithmic diagram, where all observed values for each curve have been plotted, the gauge-difference values for velocities of 3, 5, 10, and 16 ft. per sec. have been picked off. These values are given in Table 3.

6-INCH PIPE, 90° CURVE EXPERIMENTS.

Logarithmic Plotting of Observed Differential Mercury Gauge Differences, with Mean Velocities in the Pipe line, showing the Losses of Head in the Experimental Length as varied only by the introduction of the several Curves. Also the corresponding Plotting for Straight Pipe without Curvature Effects.

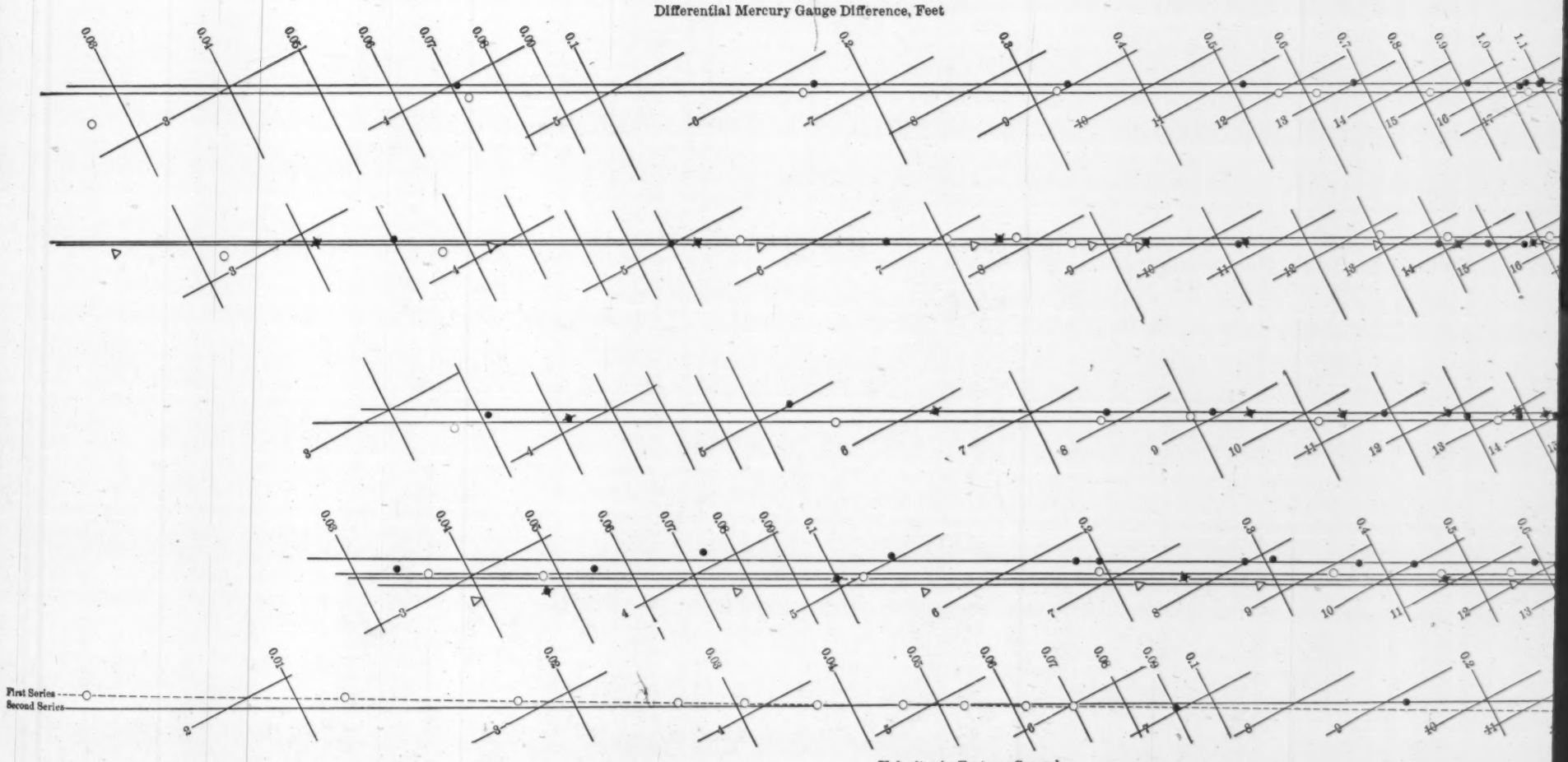
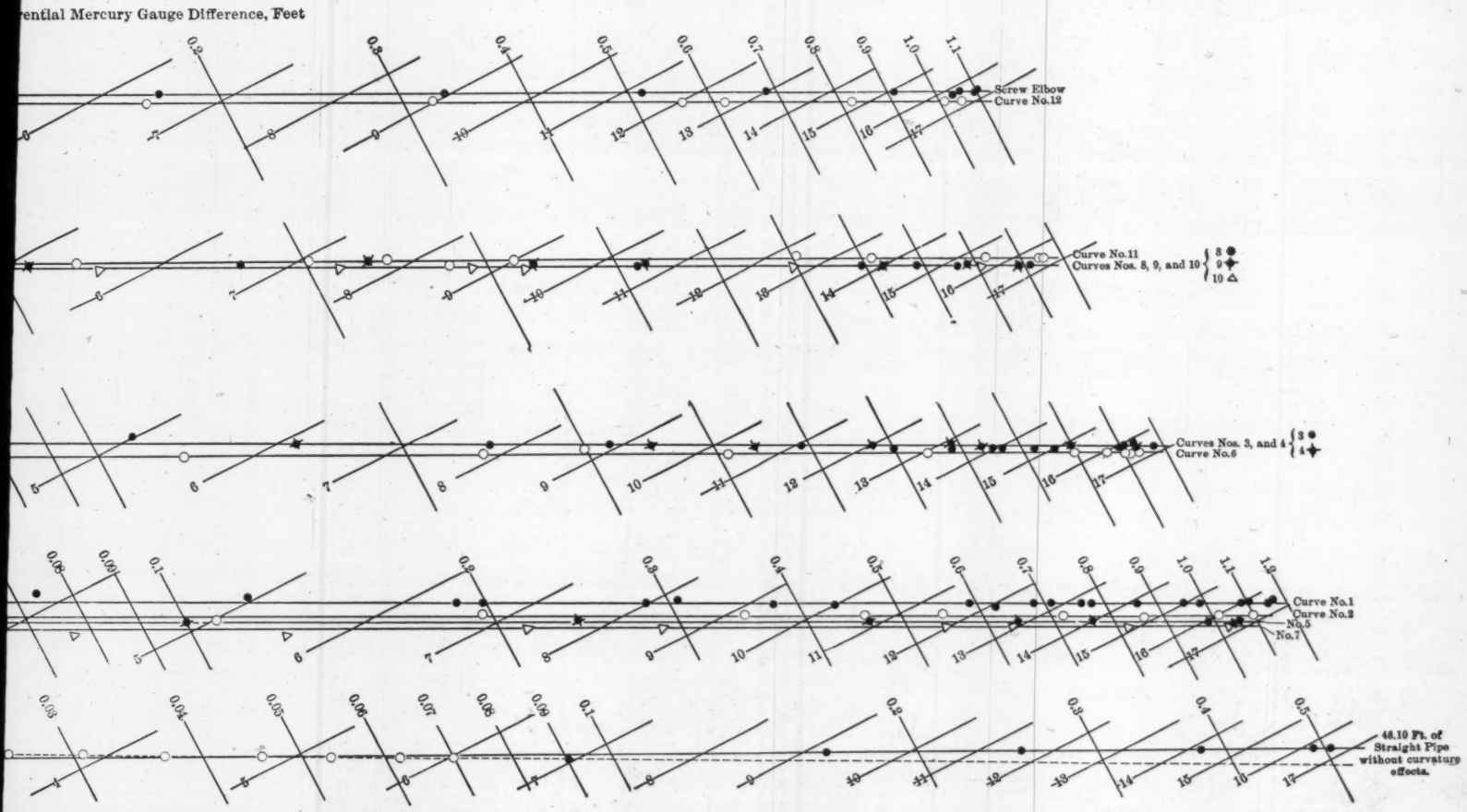


PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXII, No. 1093.
SCHODER ON
CURVE RESISTANCE IN WATER PIPES.

6-INCH PIPE, 90° CURVE EXPERIMENTS.

Logarithmic Plotting of Observed Differential Mercury Gauge Differences, with Mean Velocities in the Pipe line, showing the Losses of Head in the Experimental Length as varied only by the introduction of the several Curves. Also the corresponding Plotting for Straight Pipe without Curvature Effects.



All the cases have been reduced to the length conditions existing in the set-up for Curve No. 1. For the first comparison, the observed differential mercury-gauge differences for the other curves have been increased by an amount corresponding to the additional length of straight pipe necessary to give the same length on the center line as existed between the two piezometers when Curve No. 1 was in the pipe line. For the second comparison, the added quantity corresponds to the extra length of pipe required to make the sum of the tangent distances from the point of intersection equal to that for Curve No. 1. These two cases may be called, for brevity, respectively, the equal-lengths and the two-fixed-points cases.

TABLE 3.—DIFFERENTIAL MERCURY-GAUGE DIFFERENCES FROM THE MEAN LINES DRAWN FOR THE PLOTTED POINTS FOR ALL THE OBSERVATIONS, IN FEET.

No. of curve.	VELOCITY, IN FEET PER SECOND:			
	3	5	10	16
1	0.0444	0.1180	0.443	1.090
2	0.0408	0.1083	0.410	1.011
3	0.0400	0.1062	0.402	0.991
4	0.0400	0.1062	0.402	0.991
5	0.0395	0.1046	0.396	0.978
6	0.0376	0.1008	0.386	0.960
7	0.0381	0.1013	0.385	0.950
8	0.0375	0.1002	0.382	0.942
9	0.0375	0.1002	0.382	0.942
10	0.0375	0.1002	0.382	0.942
11	0.0382	0.1030	0.394	0.981
12	0.0387	0.1031	0.392	0.968
Screw elbow.	0.0403	0.1077	0.413	1.030

TABLE 4.—LENGTHS OF STRAIGHT PIPE TO BE ADDED TO REDUCE ALL CASES TO CONDITIONS OF CURVE NO. 1.

No. of curve.	For equal lengths on center lines.	To connect two fixed points.	No. of curve.	For equal lengths on center lines.	To connect two fixed points.
2	3.92 ft.	5.00 ft.	8	13.90 ft.	17.56 ft.
3	7.75 "	9.90 "	9	14.22 "	18.06 "
4	9.42 "	12.00 "	10	15.01 "	18.90 "
5	10.87 "	13.88 "	11	13.14 "	17.06 "
6	11.68 "	14.91 "	12	15.71 "	19.72 "
7	13.12 "	16.56 "	Screw elbow.	.....	20.56 "

Table 4 gives the length of straight pipe to be added for each curve for the two cases to reduce all to the conditions of Curve No. 1.

The loss of head per foot of length of straight pipe is given in Table 5,

Using Tables 5 and 4, the individual corrections are calculated. The results are given in Table 6.

TABLE 5.

Velocity, in feet per second.	From the First Experiments:		From the Second Experiments:	
	Mercury differential-gauge differences, in feet.	Feet of water.	Mercury differential-gauge differences, in feet.	Feet of water.
3	0.000412	0.00518	0.000899	0.00502
5	0.001071	0.01346	0.001075	0.0135
10	0.003903	0.0491	0.00412	0.0518
16	0.00943	0.1185	0.01026	0.129

TABLE 6.—Corrections to be Added to Observed Differential Mercury-Gauge Differences to Reduce All Cases for Comparison with Conditions of Curve No. 1, in Feet.

For Equal Lengths on Center Lines:					To Connect Two Fixed Points:				
No. of curve.	Velocity, in feet per second.				No. of curve.	Velocity, in feet per second.			
	3	5	10	16		3	5	10	16
On Basis of First Straight-Pipe Experiments.									
2	0.0016	0.0042	0.015	0.037	2	0.0021	0.0054	0.020	0.047
3	0.0032	0.0083	0.030	0.073	3	0.0041	0.0106	0.039	0.093
4	0.0039	0.0101	0.037	0.089	4	0.0049	0.0129	0.047	0.113
5	0.0045	0.0117	0.042	0.103	5	0.0057	0.0149	0.054	0.131
6	0.0048	0.0125	0.046	0.110	6	0.0061	0.0160	0.058	0.141
7	0.0054	0.0141	0.051	0.124	7	0.0068	0.0177	0.065	0.156
8	0.0057	0.0149	0.054	0.131	8	0.0072	0.0188	0.069	0.166
9	0.0059	0.0152	0.056	0.134	9	0.0074	0.0194	0.070	0.170
10	0.0062	0.0161	0.059	0.142	10	0.0078	0.0202	0.074	0.178
11	0.0054	0.0141	0.051	0.124	11	0.0070	0.0188	0.067	0.161
12	0.0065	0.0168	0.061	0.148	12	0.0081	0.0211	0.077	0.186
					Screw elbow	0.0085	0.0220	0.080	0.194
On Basis of Second Straight-Pipe Experiments.									
2	0.0016	0.0042	0.016	0.040	2	0.0020	0.0054	0.021	0.051
3	0.0031	0.0083	0.032	0.080	3	0.0040	0.0106	0.041	0.102
4	0.0038	0.0102	0.038	0.097	4	0.0048	0.0129	0.049	0.123
5	0.0043	0.0117	0.045	0.112	5	0.0055	0.0149	0.057	0.142
6	0.0047	0.0126	0.048	0.120	6	0.0059	0.0160	0.061	0.153
7	0.0052	0.0141	0.054	0.135	7	0.0066	0.0178	0.068	0.170
8	0.0055	0.0150	0.057	0.143	8	0.0070	0.0189	0.072	0.180
9	0.0057	0.0153	0.059	0.146	9	0.0072	0.0194	0.074	0.185
10	0.0060	0.0161	0.062	0.154	10	0.0075	0.0203	0.078	0.194
11	0.0052	0.0141	0.054	0.135	11	0.0068	0.0183	0.070	0.175
12	0.0063	0.0169	0.065	0.161	12	0.0079	0.0212	0.081	0.202
					Screw elbow	0.0082	0.0221	0.085	0.211

The values in Table 6 are added to the corresponding ones in Table 3 to obtain the losses of head when the length conditions are the same as for Curve No. 1. If, from these latter losses of head, there are subtracted the losses of head in the same length of straight pipe without curvature effects, the results are the excess losses of head due to the curves. This has been done, using the values in Table 7. The units are in feet of difference on a mercury differential gauge.

TABLE 7.

Velocity, in feet per second.	From the First Experiments:		From the Second Experiments:	
	Loss per 101.98 ft. of straight pipe, the length on center line, for Curve No. 1.	Loss per 106.27 ft. of straight pipe, the sum of the tangent distances from the P. I., for Curve No. 1.	Loss per 101.98 ft. of straight pipe.	Loss per 107.32 ft. of straight pipe.
3	0.0420	0.0438	0.0407	0.0424
5	0.1092	0.1139	0.1096	0.1142
10	0.398	0.415	0.420	0.438
16	0.962	1.002	1.046	1.190

The excess losses of head, found as above described, are given in Table 8, having been reduced to feet of water by multiplying by 12.57. (On a mercury differential gauge the difference corresponds to a water difference 12.57 times as great, the specific gravity of mercury being 13.57.)

In Table 9 these excess losses of head are expressed in terms of the lengths of straight pipe that would give the same losses. In Table 10 they are expressed in terms of the velocity heads. Tables 9 and 10 have been worked out on the basis of the second series of straight-pipe experiments only. The excess losses of head, given in Table 8, are plotted on Figs. 3, 4, 5, and 6, to show the relation to the radius of curvature. The points have been connected by short straight lines, no attempt being made to draw smooth averaging curves. The results given in Table 9 have been plotted in the same manner in Figs. 7 and 8. The results are now in shape for discussion on the influence of curvature.

Fig. 5 indicates for increasing radius of curvature a decided lessening in the excess loss of head throughout the range of the experiments. Fig. 3 seems to indicate on the whole a gradual decrease

as the radius of the curve increases above about 1.25 ft., or 2½ diameters. Certainly, there is no general indication of an increasing loss of head.

TABLE 8.—Excess Loss of Head of Straight Pipes Joined by a 90° Curve over Straight Pipe Alone, in Feet of Water.

For Equal Lengths on Center Lines:					To Connect Two Fixed Points:				
No. of curve.	Velocity, in feet per second.				No. of curve.	Velocity, in feet per second.			
	3	5	10	16		3	5	10	16
On Basis of First Straight-Pipe Experiments.									
1	0.030	0.111	0.57	1.61	1	0.007	0.052	0.35	1.11
2	0.005	0.041	0.34	1.09	2	—0.011	—0.002	0.19	0.71
3	0.006	0.067	0.43	1.29	3	0.004	0.037	0.33	1.04
4	0.024	0.089	0.52	1.49	4	0.014	0.066	0.43	1.29
5	0.025	0.089	0.50	1.50	5	0.018	0.071	0.44	1.35
6	0.005	0.051	0.43	1.36	6	—0.001	0.037	0.36	1.25
7	0.019	0.078	0.48	1.41	7	0.014	0.064	0.44	1.31
8	0.006	0.074	0.48	1.40	8	0.011	0.064	0.45	1.34
9	0.018	0.078	0.50	1.44	9	0.014	0.072	0.46	1.39
10	0.021	0.089	0.54	1.54	10	0.019	0.082	0.52	1.49
11	0.020	0.099	0.59	1.80	11	0.018	0.093	0.58	1.76
12	0.040	0.134	0.69	1.94	12	0.038	0.130	0.68	1.91
					Screw elbow.	0.063	0.199	0.98	2.79
On Basis of Second Straight-Pipe Experiments.									
1	0.047	0.105	0.29	0.57	1	0.025	0.047	0.06	0.00
2	0.021	0.035	0.07	0.06	2	0.005	—0.007	—0.09	—0.35
3	0.030	0.061	0.17	0.32	3	0.020	0.032	0.06	0.04
4	0.039	0.084	0.26	0.53	4	0.030	0.060	0.16	0.30
5	0.039	0.083	0.26	0.55	5	0.033	0.066	0.19	0.38
6	0.020	0.047	0.17	0.43	6	0.014	0.032	0.11	0.29
7	0.033	0.072	0.24	0.49	7	0.029	0.060	0.19	0.38
8	0.029	0.069	0.24	0.49	8	0.026	0.060	0.20	0.40
9	0.031	0.073	0.26	0.53	9	0.029	0.067	0.23	0.47
10	0.035	0.083	0.30	0.63	10	0.033	0.078	0.28	0.58
11	0.034	0.093	0.35	0.88	11	0.033	0.088	0.33	0.83
12	0.054	0.130	0.45	1.05	12	0.053	0.126	0.44	1.01
					Screw elbow.	0.077	0.195	0.75	1.90

Figs. 4 and 6 show how the results are modified when the results of the first straight-pipe experiments are used. Fig. 4, especially, is of interest in comparison with Fig. 3. Both are based on the equal-lengths comparison. In Fig. 3 the excess loss tends to approach zero for the long-radius curves, but, in Fig. 4, the average excess appears to be nearly constant for the longer radii. If this latter constant

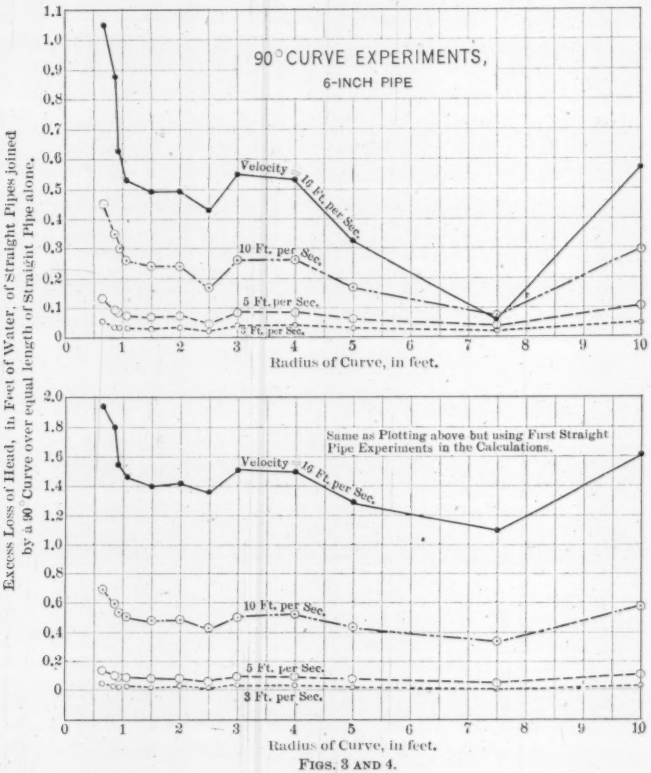
TABLE 9.—LENGTHS OF STRAIGHT PIPE, IN FEET, TO GIVE LOSS OF HEAD EQUAL TO THE EXCESS LOSS DUE TO THE CURVES. ON THE BASIS OF THE SECOND STRAIGHT-PIPE EXPERIMENTS.

FOR EQUAL LENGTHS ON CENTER LINES:					TO CONNECT TWO FIXED POINTS:				
No. of curve.	Velocity, in feet per second.				No. of curve.	Velocity, in feet per second.			
	3	5	10	16		3	5	10	16
1	9.4	7.8	5.6	4.3	1	5.0	3.4	1.2	0.0
2	4.2	2.6	1.4	0.5	2	1.0	—0.6	—1.7	—2.7
3	6.0	4.5	3.3	2.5	3	4.0	2.3	1.2	0.3
4	7.8	6.2	5.1	4.1	4	6.0	4.4	3.1	2.3
5	7.8	6.1	5.1	4.3	5	6.6	4.8	3.7	3.0
6	4.0	3.5	3.3	3.3	6	2.8	2.3	2.2	2.3
7	6.6	5.3	4.7	3.8	7	5.8	4.4	3.7	3.0
8	5.8	5.1	4.7	3.8	8	5.2	4.4	3.9	3.1
9	6.2	5.4	5.1	4.1	9	5.8	4.9	4.5	3.7
10	7.0	6.2	5.8	4.9	10	6.6	5.7	5.4	4.5
11	6.8	6.9	6.8	6.8	11	6.6	6.5	6.4	6.4
12	10.8	9.6	8.9	8.1	12	10.6	9.3	8.5	7.8
					Screw elbow.	15.3	14.4	14.5	14.7

TABLE 10.—EXCESS LOSSES OF HEAD DUE TO CURVES, EXPRESSED IN TERMS OF VELOCITY HEADS. ON THE BASIS OF THE SECOND STRAIGHT-PIPE EXPERIMENTS.

FOR EQUAL LENGTHS ON CENTER LINES:					TO CONNECT TWO FIXED POINTS:				
No. of curve.	Velocity, in feet per second.				No. of curve.	Velocity, in feet per second.			
	3	5	10	16		3	5	10	16
	$\frac{V^2}{2g} = 0.1397$	$\frac{V^2}{2g} = 0.3882$	$\frac{V^2}{2g} = 1.553$	$\frac{V^2}{2g} = 3.975$					
1	0.34	0.27	0.19	0.14	1	0.18	0.12	0.04	0.00
2	0.15	0.09	0.05	0.02	2	0.04	—0.02	—0.06	—0.09
3	0.21	0.16	0.11	0.08	3	0.14	0.08	0.04	0.01
4	0.28	0.22	0.17	0.13	4	0.21	0.15	0.10	0.08
5	0.28	0.21	0.17	0.14	5	0.24	0.17	0.12	0.10
6	0.14	0.12	0.11	0.11	6	0.10	0.08	0.07	0.07
7	0.24	0.18	0.16	0.12	7	0.21	0.15	0.12	0.10
8	0.21	0.18	0.16	0.12	8	0.19	0.15	0.13	0.10
9	0.22	0.19	0.17	0.13	9	0.21	0.17	0.15	0.12
10	0.25	0.21	0.19	0.16	10	0.24	0.20	0.18	0.15
11	0.24	0.24	0.23	0.22	11	0.24	0.23	0.21	0.21
12	0.39	0.33	0.29	0.26	12	0.38	0.32	0.28	0.25
					Screw elbow.	0.55	0.50	0.48	0.48

tendency represents the truth, then a remarkable dilemma is presented. As the curvature of a pipe becomes less and less, the external conditions approach nearer to those of straight pipe. The natural inference is that the loss of head also approaches straight-pipe values, unless, indeed, it be argued that the slightest deflection from straight pipe immediately causes a considerable excess loss of head.* For-



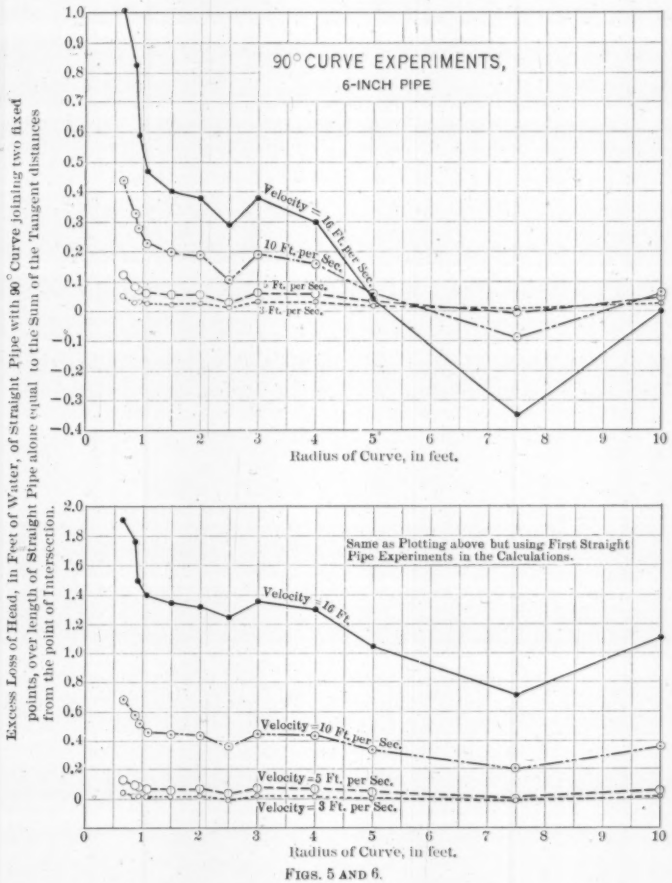
FIGS. 3 AND 4.

tunately, there exist experimental data which will assist in the consideration of these points. These will be given presently.

Fig. 6 shows the same tendency as Fig. 5, although the decrease in loss of head with increasing radius of curvature is less decided on the basis of the first straight-pipe experiments.

*Detroit Curve Experiments. *Transactions*, Am. Soc. C. E., Vol. XLVII, 1902, Conclusion *J*, page 191, and pages 186–187.

As to the difference found between the results of the two straight-pipe series, the following may be stated. Conditions of temperature were favorable for some rusting during September, after the first straight-pipe series and before the first curve experiments were made.



FIGS. 5 AND 6.

During the curve experiments, the data show no indication of increasing roughness, or of any effect of changes in temperature of the water.* All the straight pipes had been used in a steam-heating main

*This is remarkable. It has been observed, for smooth brass pipes of all sizes between $\frac{1}{8}$ in. and 5 in. in diameter, that the loss of head is increased about 4% for a decrease of temperature of the water of 10° fahr. Rougher pipes, such as galvanized iron and wrought iron, show no effect due to temperature changes.

for some years, and all seemed to have a uniform internal appearance. The first series had no velocities greater than 6 ft. per sec., while the second series had velocities as high as in the curve experiments. A

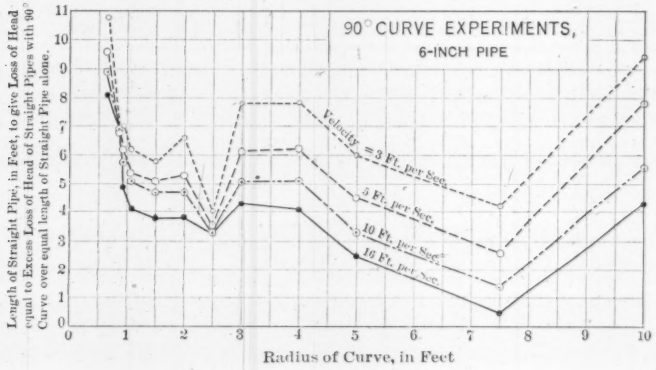


FIG. 7.

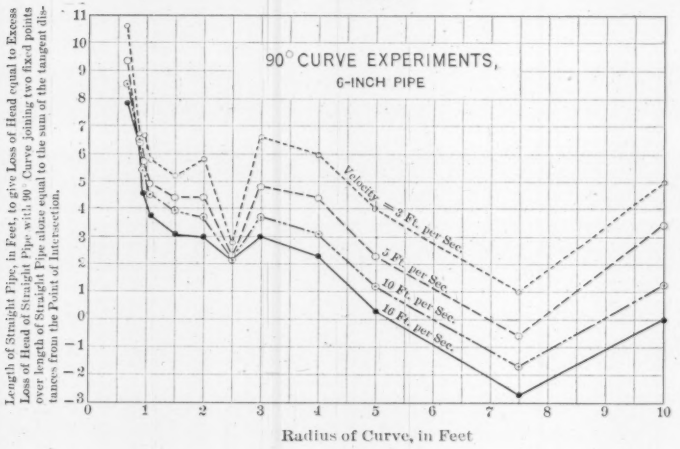


FIG. 8.

separate measurement of the loss of head in Pipes Nos. 2 and 3 when uninfluenced by curvature was not made, and it is impossible to decide as to their hydraulic properties as compared with Pipes Nos. 4 and 5.

It is thus clear that, without additional evidence, it is not possible to reject one of the straight-pipe series and accept the other, or to feel safe in using average values.

In relation to this matter, the writer desires to present the data from measurements on an 8-in. cast-iron water main. This main supplies raw water to the Cornell University Filtration Plant.* It had been laid and in use for three years before the experiments in the fall of 1906. Before laying, the inside diameter of each length had been calipered. At the time of laying, each pipe length was set accurately to line and grade with a transit. After laying, and before covering

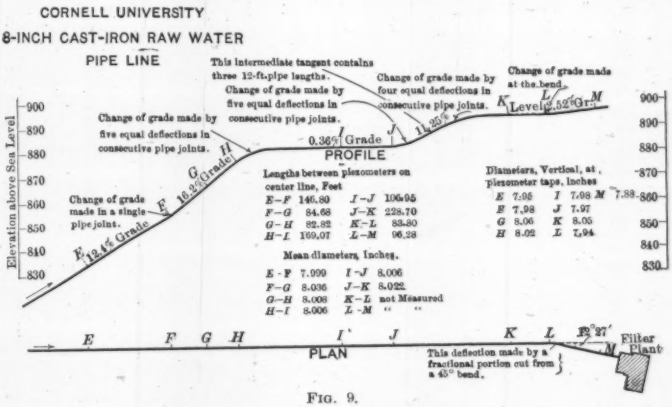


FIG. 9.

the pipe, the piezometer holes were drilled and tapped, and the diameters measured at these points; the ½-in. brass piezometer cocks were inserted so as not to project inside, and the lengths between the piezometers were measured and checked in the ditch.

The plan and profile of the pipe line are shown by Fig. 9. There are eight experimental sections, four of which contain deflections, and four of which are straight, preceded by considerable lengths of straight pipe.

The piezometer taps were placed on top of the pipe and 1 ft. up stream from the joints, except that those before deflections were placed 2 ft. up stream from the joint where the first deflection occurred.

The flow in the pipe line was measured at the filter plant by a

*Designed by G. S. Williams, M. Am. Soc. C. E. See *The Engineering Record*, April 9th, 1904.

Venturi meter which had been accurately calibrated in place by volumetric measurements. A differential water gauge was used with the meter. The losses of head were measured with a portable differential water gauge mounted on a tripod. The gauge was set up on the ground midway between two piezometer wells, and pressure connections were made with small three-ply rubber hose after thoroughly blowing off to remove all air.

The flow was controlled by a valve at the filter plant. It was possible to shut this valve down entirely, and thus get no-flow conditions and a check on the gauge readings. The electric motor-driven two-stage centrifugal pumps at the lower end of the pipe line allowed this procedure without any trouble.

After changing the valve setting and allowing the flow to become steady, simultaneous readings were taken on the meter and the loss-of-head gauges. The results are shown graphically in Figs. 10 and 11. For the straight sections the observed losses of head have been reduced uniformly to loss per 1 000 ft. It will be seen on Fig. 10 that the straight sections differ among themselves. Thus Section *E-F* has less and Section *K-L* has greater loss of head than the average of the four sections; in fact, Section *K-L* has about 15% greater loss of head than Section *E-F*. The equation of the mean line for the four sections of straight pipe is

$$H = 0.586\ V^{1.91}$$

where H is the loss of head, in feet per 1 000 ft., and V is the velocity, in feet per second. (The corresponding values of C, in $V = C\sqrt{RS}$. are: at 1 ft. per sec., 101; at 4 ft. per sec., 107.)

Fig. 11 shows the difference between this average law of flow for the straight portions and the hydraulics of the sections containing deflections. It is remarkable that Section *F-G* with a single 3.8° deflection, Section *H-I* with a curve composed of five 3.17° deflections, and Section *J-K* with a reverse curve composed of one curve with five 2.18° deflections and another with four 2.81° deflections, all show, on the whole, less loss of head than the average of equal lengths of straight pipe. Section *L-M*, with a short-radius bend giving a deflection of 12° 56′, is the only one showing a greater loss of head.

The writer does not argue from this that such easy curves or deflections are more favorable for the flow of water than straight pipe, but he does see the indication that any difference is very small and

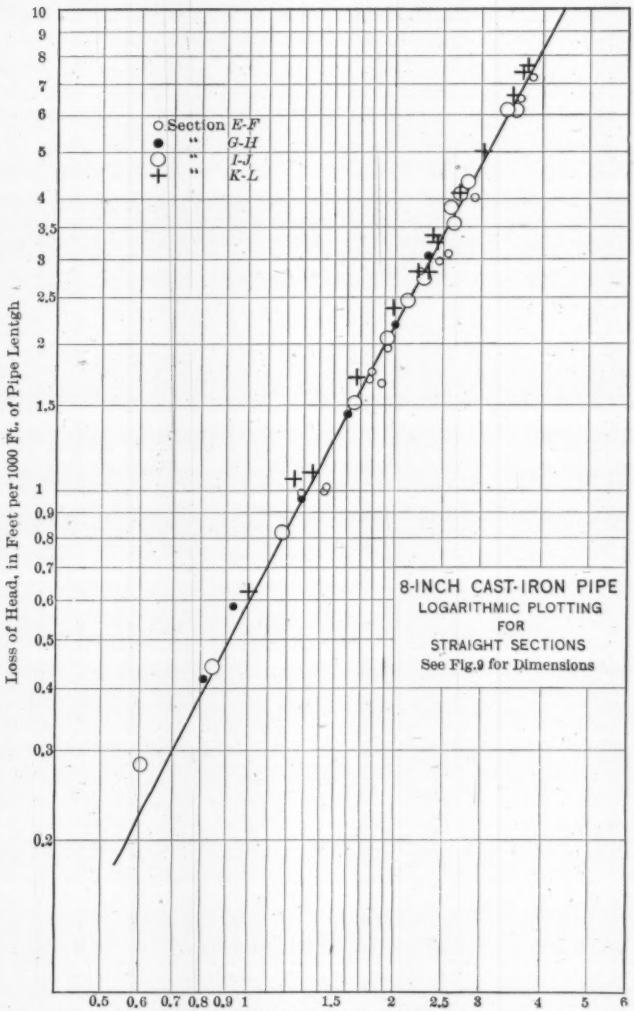

Section E-F
" G-H
" I-J
" K-L
8-INCH CAST-IRON PIPE
LOGARITHMIC PLOTTING
FOR
STRAIGHT SECTIONS
See Fig.9 for Dimensions
Loss of Head, in Feet per 1000 Ft. of Pipe Length
Velocity, in Feet per Second
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.5 0.6 0.7 0.8 0.9 1 1.5 2 2.5 3 4 5 6

FIG. 10.

may be less than the difference between two straight sections in the same pipe line, as occurs in the case above recorded.

The 6-in. wrought-iron pipe experiments also give some information on the question of the effect of slight deflections in otherwise straight pipe. The first series, of October 10th, 1907, was made with a decidedly zigzag appearance of the down-stream tangent, that is, the joints were not in a straight line, although the individual pipe lengths themselves were straight. On October 12th the series was repeated, but with the down-stream tangent carefully aligned. No difference in results is noticeable.

Viewed in the light of the foregoing, it is easy to decide that the first 6-in. straight-pipe experiments do not apply to the later curve experiments because the deduced excess loss of head does not continue to approach zero for the long easy curves. In this respect, the difference between Figs. 3 and 4 is noteworthy.

Now, all of this contradicts the findings of Messrs. Williams, Hubbell, and Fenkell in the Detroit Experiments. The writer cannot imagine that radically different laws apply to the cases investigated by him and by these experimenters.

One difference in conditions is to be noted, however. The long-radius curves in the 30-in. Detroit main were made up of several pieces, while the writer's 6-in. curves were all one-piece bends. As to the probable small effect of the joints, the writer's 8-in. pipe experiments, with small deflections, give some idea; but there are other possible causes for the divergence of the findings. The smallness of the measured losses, with the comparatively low velocities available in the Detroit 30-in. main, would tend to magnify excess losses due to other effects than curvature. Thus, in Figs. 3 and 5 it will be seen that a very different appeal to the eye is given by the line for a velocity of 16 ft. per sec. than by the line for a velocity of 3 or even 5 ft. per sec.

There remains, also, for the Detroit Experiments, the possibility of relatively large errors due to several causes. These errors were considered by Messrs. Williams, Hubbell, and Fenkell in their closing discussion, and a table was presented* in which corrections—as large as 50% in one case—were made to the results given in the main part of the paper. These corrections materially alter the appearance of the remarkable Fig. 90 of the paper.

*Table No. 89, page 360, *Transactions*, Am. Soc. C. E., Vol. XLVII, 1902.

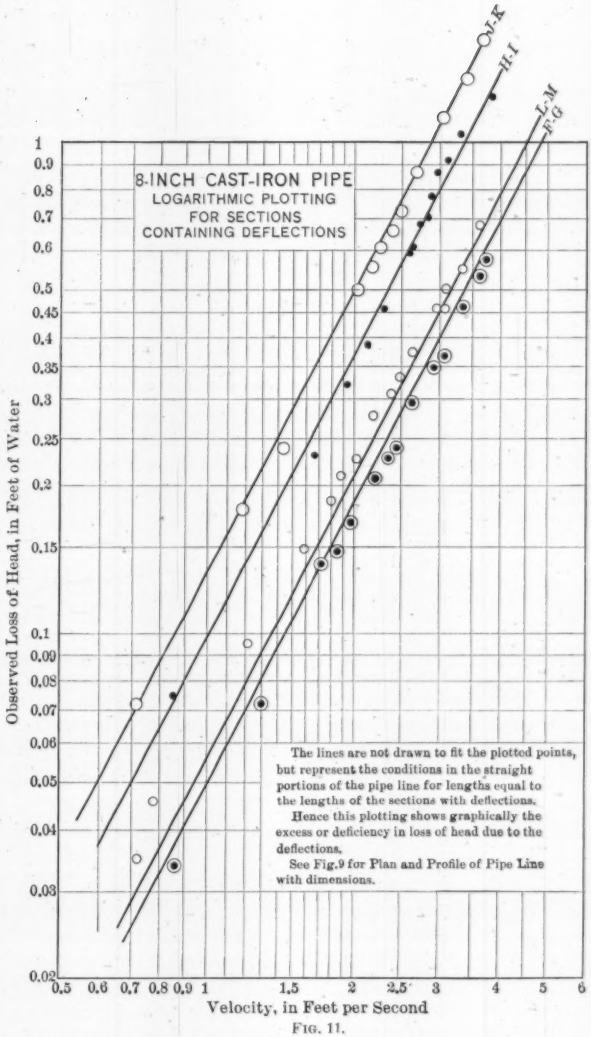

8-INCH CAST-IRON PIPE
LOGARITHMIC PLOTTING
FOR SECTIONS
CONTAINING DEFLECTIONS
J-K
H-I
L-M
F-G
Observed Loss of Head, in Feet of Water
1
0.9
0.8
0.7
0.6
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.5 0.6 0.7 0.8 0.9 1 1.5 2 2.5 3 4 5 6
Velocity, in Feet per Second
The lines are not drawn to fit the plotted points, but represent the conditions in the straight portions of the pipe line for lengths equal to the lengths of the sections with deflections.
Hence this plotting shows graphically the excess or deficiency in loss of head due to the deflections.
See Fig. 9 for Plan and Profile of Pipe Line with dimensions.

FIG. 11.

If, now, in the Detroit Experiments, to the causes for incorrect deductions above mentioned there be added the effect of using for comparison the results of experiments on short sections of straight pipe that might have had quite different hydraulic properties from the straight pipe in the curve section, it is easy to see that the combination of circumstances may have led to conclusions not at all general in their applicability, and perhaps even wrong for the case in hand; but, as to this matter, the writer is quite content with suggesting the salient arguments.

After all, however, the engineer will be particularly interested in the magnitude of the excess losses of head due to curves. Are they seriously large in an extreme case?

Figs. 7 and 8 show that the excess loss of head for the shortest 90° curve is equal to the loss in 7 to 10 ft. (or 14 to 20 diameters) length of straight pipe. When the radius is 2½ diameters the excess loss of head is equal to the loss in 5 to 10 diameters length of straight pipe. In this relation Fig. 12 is interesting. It is seen that, for the smooth brass 180° curves, the excess loss of head is rather less than the loss of head in 7 diameters length of straight pipe. The expression, $0.15 = \frac{V^2}{2g}$, seems to give a fair average value for the range of these brass-curve experiments.

Table 9 shows that the 6-in. screw elbow gives an excess loss of head equal to the loss in about 27 diameters length of straight wrought-iron pipe. The writer has also the record of some accurate measurements on the loss due to 3-in. and 4-in. screw elbows, from which it appears that the losses are equal, respectively, to the losses in 25 and 27 diameters length of straight wrought-iron pipe.

When, therefore, the Detroit Experiments, after thorough revision, indicate for a long easy curve in 30-in. pipe an excess loss of head equal to the loss in 50 diameters length of straight pipe, not only does the loss seem to be too large when compared with the loss in a screw elbow where sudden enlargement and contraction are present in addition to extremely short-turn curvature effects, but the whole trend of the results is directly the opposite of what is shown by the writer's experiments on 6 and 8-in. pipes.

Now, it may be that Nature changes her methods somewhere between pipes of 8 and 30 in. in diameter, as regards the effects of

curvature. It must be so, if both the Detroit Experiments and those of the writer have been interpreted correctly. The evidence seems to stand as follows: In Detroit, with a small range of low velocities (the greatest about 3 ft. per sec.) the 30-in. pipe line shows an increas-

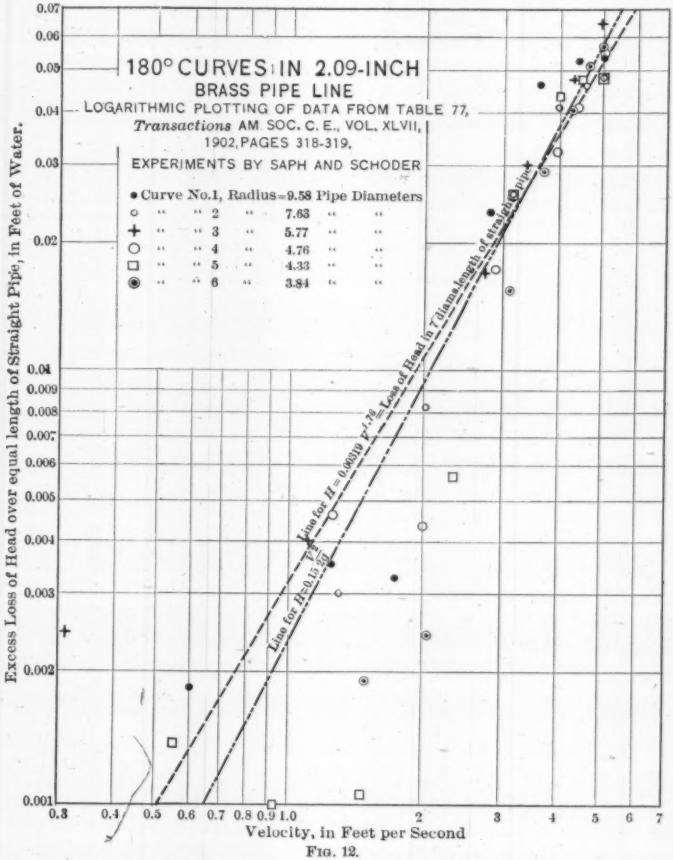


FIG. 12.

ing loss of head with increasing radius of curvature for curves with radii between 5 and 25 diameters. (The other pipe lines, 12 and 16-in., have only short-radius curves, and the results are not consistent.) The writer's experiments on 6-in. pipe, with velocities up to 16 ft. per sec.,

show the opposite. His 8-in. pipe experiments indicate no measurable excess loss of head for bends composed of a series of small deflections at consecutive joints in ordinary cast-iron pipe, and his 6-in. pipe also shows no appreciable excess loss for several small deflections. The quantitative results for the long Detroit 30-in. 90° curves are far in excess of the 180° 2-in. brass curves, the writer's 6-in. 90° curves, the 3, 4 and 6-in. screw elbows, and, as above stated, are contradicted by the no-excess results of the 8-in. long, easy curves.

If, then, for any reason, an engineer wishes to use a long, easy curve, or a series of small deflections, in the joints between straight pipes, the writer's experiments indicate just what most hydraulic engineers have assumed, namely, that there is practically no difference between the loss of head due to a long, easy curve and that due to an equal length of straight pipe.

No calculations on the basis of the loss of head per foot length of curved portion have been made, because all the excess loss of head probably does not occur in the curve, an unknown part of the loss taking place in the down-stream tangent in the region where the abnormal flow returns to normal. Partly for this reason, also, it was not deemed wise to attempt any correction on account of the smaller diameter of the 6-in. cast-iron curves, or, indeed, on account of the variation in the diameters of any of the curves from the mean diameter of the straight pipe. Besides, we have no precise knowledge concerning the effects of slight sudden enlargements or contractions, such as are involved in these experiments.

The writer has found this an interesting study, and would gladly have extended the experiments to other sizes of pipes, but the cost, in time and money, is rather large. He would suggest the desirability of similar studies on other small sizes, and of many further experiments on curves in existing large pipe lines.

The writer desires to acknowledge his indebtedness to Professor W. B. Gregory, who worked with him throughout the 6-in. pipe experiments, and in subsequent Pitot tube investigations* in the course of which it was shown that normal flow prevailed at all the piezometers in the 6-in. pipe.

After preparing this paper, the writer's attention was called to a

* See paper, "Some Pitot Tube Studies," by W. B. Gregory and E. W. Schoder, *Proceedings*, Am. Soc. Mech. Engrs., May, 1908.

record of experiments on 90° bends in 3 and 4-in. pipes.* These experiments covered a right-angled elbow and right-angled bends having radii equal to 2, 4, 6, 8, 10, 12, and 14 diameters in 3-in. pipe, and the same, excepting the last two, in 4-in. pipe.

The arrangement resembled that by the writer except that the down-stream piezometer was located rather close to the curves, being 6 ft. 8 in., or 27 diameters, distant for the 3-in. pipe, and from 5 ft. to 6 ft. 7¼ in., or from 15 to 19 diameters, distant for the 4-in. pipe. The length of straight pipe up stream from the up-stream piezometer was 7 ft. for both the 3 and 4-in. pipes.

Fig. 13 is a reproduction of Mr. Brightmore's plotting of the results of his experiments. There is a striking similarity between the

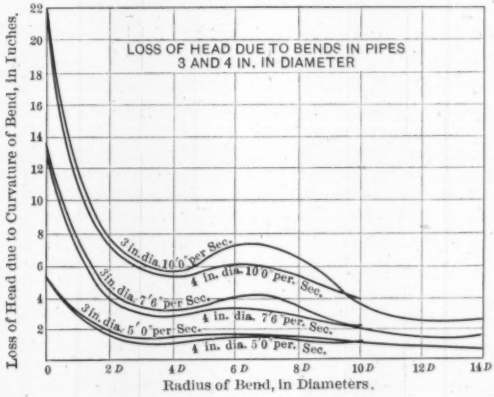


FIG. 13.

shape of his curves and those by the writer in Fig. 3 (which corresponds to Fig. 13). The hump in the curves between 6 and 8 diameters appears in both Figs. 3 and 13. The quantitative results are not readily compared. For Mr. Brightmore's 4-in. pipe the straight pipe (rusted cast iron) had a coefficient of 47.5 in the formula, $V = C\sqrt{RS}$. For the 3-in. pipe (galvanized) the coefficient was 65 to 70 for V ranging from 3 to 11 ft. per sec. In the writer's experiments, the coefficient for the 6-in. wrought-iron pipe was 119 to 125 for V ranging

* Paper No. 3679, "Loss of Pressure in Water Flowing through Straight and Curved Pipes," by Arthur William Brightmore, M. Inst. C. E., *Minutes of Proceedings*, Inst. C. E., Vol. CLXIX, 1906-1907, p. 323.

from 3 to 16 ft. per sec. Mr. Brightmore purposely allowed the pipes and curves to become rusted, but, he states, not tuberculated. The foregoing figures indicate that he was working with much rougher pipes than the writer used, and the quantitative values shown on Fig. 13 indicate the same in comparison with Fig. 3.

It is evident that further experiments are desirable before precise laws can be stated, although the qualitative results by Mr. Brightmore and the writer agree in indicating a decreasing loss of head for an increasing radius of curvature.

DISCUSSION.

GEORGE JACOB DAVIS, JR., ASSOC. M. AM. SOC. C. E. (by letter).— During the past six months some experiments on curve resistance in water pipes have been made, under the writer's direction, in the Hydraulic Laboratory of the University of Wisconsin. A description of these experiments and a discussion of the results are given in the hope of throwing some additional light on the subject. Mr. Davis.

The experiments were first undertaken in the spring by Messrs. H. Hosler, C. M. Kehr, and R. K. McComb as a graduating thesis in the College of Mechanics and Engineering. They were continued during the summer school session by Messrs. A. F. Coleman, C. M. Kehr, and B. M. Reynolds. Credit is due these gentlemen for the diligent care exercised in making the observations and most of the computations.

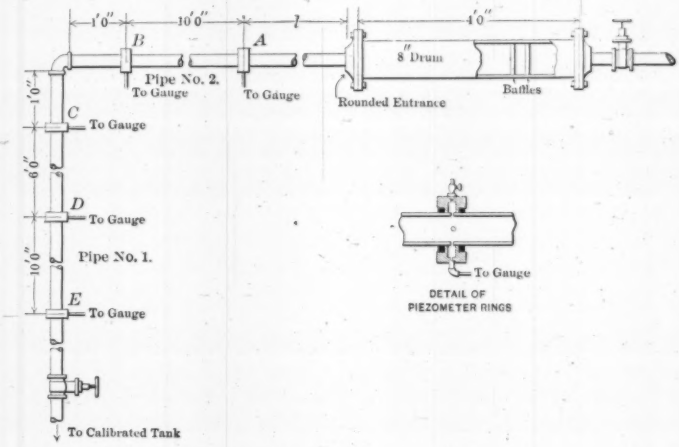


FIG. 14.

The apparatus, which forms part of the equipment used in the regular course of instruction in experimental hydraulics, is shown in Fig. 14. The pipes, marked "Pipe No. 1" and "Pipe No. 2," were lap-welded pipes of iron or steel, and were new at the beginning of the work. The nominal size was 2 in., but the actual internal diameter was $2\frac{1}{16}$ in. In all computations of velocities, ratios of radius to diameter, etc., the actual diameter was used. The piezometers, as shown in Fig. 14, consisted of four $\frac{1}{4}$-in. holes drilled through the pipe walls, 90° apart, and communicating with an equalizing chamber,

Mr. Davis. which led to the gauges, and from which accumulated air could be allowed to escape. Water differential gauges were used to measure the loss of head. The water was measured in a galvanized-iron tank of 50 cu. ft. capacity, and the time was observed with a stop-watch. During the spring experiments the length of pipe between the drum and the first piezometer, marked *"l"* on Fig. 14, was only 9 ft., and while calibrating Pipe No. 1 this distance was only 3 ft. It was believed that normal flow in the pipe had not obtained in so short a distance from the rounded entrance to the pipe; therefore, in the summer experiments, the length, *"l,"* was made 62 ft.

The loss of head due to friction in the straight pipes was determined for both pipes before the baffles, shown in Fig. 14, were placed in the drum. A second determination was made for Pipe No. 2 after installing the baffles, and no change was noticed in the friction loss, but the gauges were steadier. At the completion of the spring work, the friction loss was again determined for both pipes. Only a slight difference was noticed, due probably to rusting of the pipes. At the completion of the summer work, the friction loss was again determined for both pipes. This determination gave a loss of head per foot length of pipe equal to

$$h = 0.00240\, v^{1.85}$$

The loss per foot was the same in both pipes. The results of the friction loss determinations are plotted logarithmically in Fig. 15. Only the curve representing the last determinations was drawn. As may be seen from Fig. 15, a line through the points of the earlier determinations would have had a flatter slope and would have lain above the one drawn, up to a velocity of about 10 ft. per sec., at which point the lines cross. It is believed that the effect of rusting would have raised the line instead of lowering it, and the lower values of the friction loss are believed to be due to a steadier and more normal flow at the greater distance from the drum. All the curves having a ratio of radius of curvature to diameter of pipe equal to or greater than $2\frac{1}{2}$ were experimented on under the improved conditions; moreover, during all measurements of loss due to elbows, the nearest piezometer was 19 ft. from the drum. It was thought, therefore, that the nearest estimate of the friction loss was obtained by using the curve drawn in Fig. 15. Any errors due to uncertainty regarding the value of the pipe friction would be small, and would only affect the short-radius curves, the losses in which are large.

All the curves experimented on made a turn of 90°, and had radii of curvature as given in Table 11.

Nos. 1 to 6, inclusive, were standard fittings purchased from the Crane Company. No. 7 was cast from a pattern made in the shop of the mechanician of the Engineering College. Nos. 9 and 10 were bent from 2-in. pipe by the University blacksmith.

Mr. Davis.

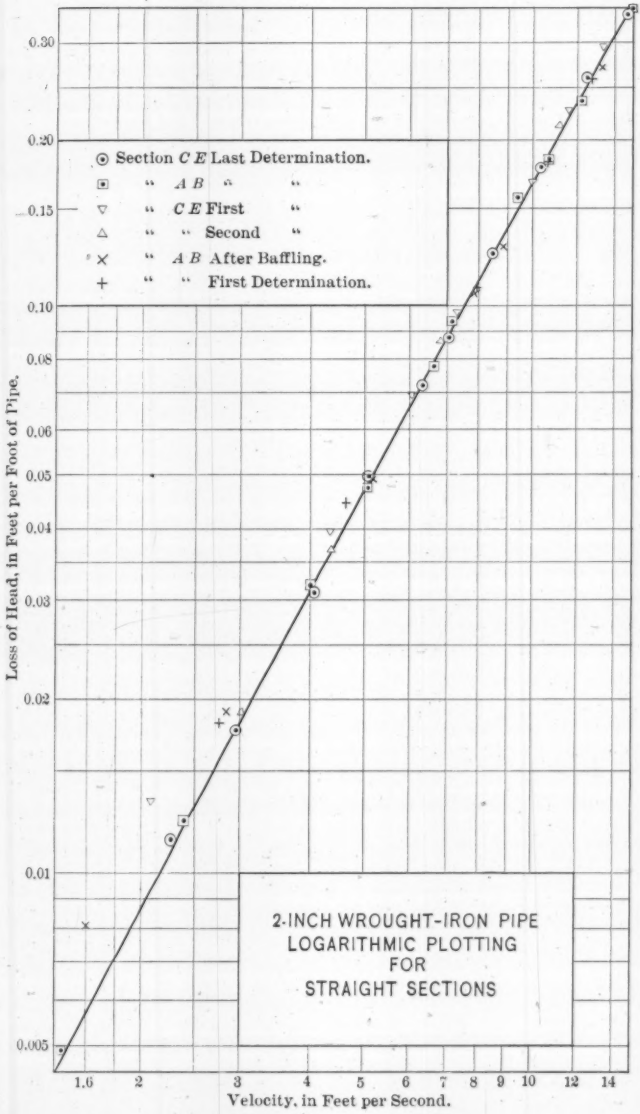


FIG. 15.

Mr. Davis.

TABLE 11.

No.	Description.	Internal diameter of elbow, in inches.	$\frac{R}{d}$
1	Malleable-iron elbow	$2\frac{3}{8}$	0.788
2	Cast-iron, long-turn, drainage elbow	$2\frac{1}{16}$	1.150
3	Cast-iron, drainage elbow	$2\frac{1}{16}$	0.728
4	Cast-iron, short turn	$2\frac{3}{8}$	0.728
5	Cast-iron, long sweep	$2\frac{3}{32}$	1.520
6	Cast-iron tee	...	0
7	Cast-iron	$2\frac{1}{16}$	2.500
8	Wrought-iron or steel	$2\frac{1}{16}$	5.000
9	" " " "	$2\frac{1}{16}$	10.000

Drawings of Elbows Nos. 1 to 6, inclusive, are shown in Fig. 16. No. 7 was similar to Nos. 2 and 3; the only difference being in the longer radius of curvature. Nos. 8 and 9 were fitted with ordinary flanges, no attempt being made to obtain a flush joint.

While experimenting on the loss due to the curves, the loss of head was read by three separate water differential gauges; the first being connected between Piezometers *B* and *C* (Fig. 14); the second between Piezometers *C* and *D*, and the third between Piezometers *D* and *E*. The results show that the curves caused a great increase in loss of head in Sections *B-C* and *C-D*, but none in Section *D-E*, even in the case of the tee which caused the greatest total loss of head. Therefore, it is safe to conclude that, by reading the head between Piezometers *B* and *E*, the entire loss caused by the curves was included. The results were all worked up on this basis.

A summary of the data is given in Table 12. Each value of v, which represents the actual mean velocity in the pipe, is the average for several runs taken under identical conditions, except for very slight variations in flow due to pressure changes in the supply mains. Likewise, the value of H_1, which represents the loss of head between Piezometers *B* and *E*, is the average for several runs, the gauges having been read from five to ten or more times during each run.

Discussion of Results.

In discussing the results of experiments on curve resistance, confusion may arise on account of the many ways in which the problem may be considered. Professor Schoder has presented his results worked up on two different bases. The results of the writer's work were studied on five different bases, and the results are compared in curves *A*, *B*, *C*, *D*, and *E*, in Figs. 18 and 19.

Case A.—In Case *A* the writer has assumed that a straight pipe, the friction factor of which is already known, is to be bent into a curve of some given radius, and it is desired to know how much more the loss of head will be than in the straight condition. This is the

Mr. Davis.

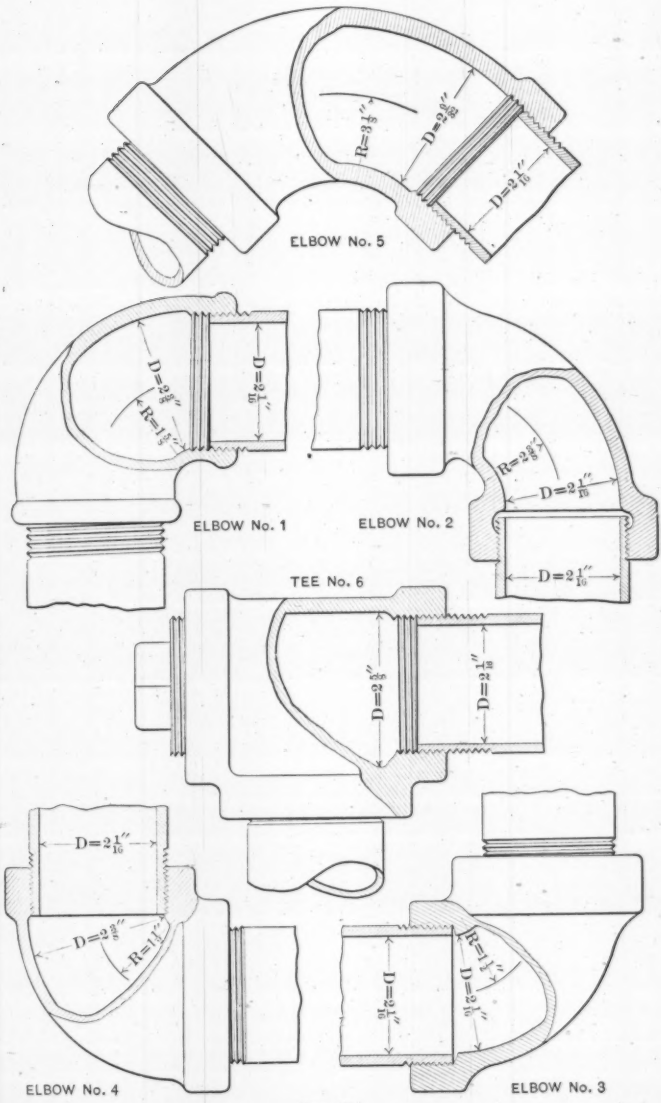


FIG. 16.

TABLE 12.—Summary of Data.

Pipe No. 1.

First Determination of Friction.		Second Determination of Friction.		Last Determination of Friction.	
Velocity, in feet per second.	Loss of head, in feet per foot of pipe.	Velocity, in feet per second.	Loss of head, in feet per foot of pipe.	Velocity, in feet per second.	Loss of head, in feet per foot of pipe.
2.087	0.0133	3.02	0.0189	2.25	0.01133
4.30	0.0396	4.35	0.0365	2.95	0.01762
6.08	0.0592	6.85	0.0863	4.05	0.03077
7.31	0.0968	11.20	0.2110	5.07	0.04940
9.90	0.1667	.....	.....	6.34	0.07188
11.60	0.2240	.....	.....	7.05	0.0876
13.40	0.2936	.....	.....	8.48	0.1235
.....	.....	.....	.....	10.28	0.1762
.....	.....	.....	.....	12.45	0.2585
.....	.....	.....	.....	14.70	0.3388

Pipe No. 2.

First Determination of Friction.		Determination of Friction after Baffling.		Last Determination of Friction.	
Velocity, in feet per second.	Loss of head, in feet per foot of pipe.	Velocity, in feet per second.	Loss of head, in feet per foot of pipe.	Velocity, in feet per second.	Loss of head, in feet per foot of pipe.
2.75	0.0182	1.60	0.0081	1.43	0.0049
4.64	0.0441	2.84	0.0190	2.38	0.0122
7.93	0.1075	5.14	0.0490	4.00	0.0317
10.57	0.1821	7.85	0.1058	5.05	0.0471
12.60	0.2560	8.84	0.1272	6.64	0.0774
.....	.....	13.30	0.2690	7.17	0.0935
.....	.....	.....	.....	9.33	0.1503
.....	.....	.....	.....	10.57	0.1840
.....	.....	.....	.....	12.03	0.2324
.....	.....	.....	.....	14.79	0.3455

Elbow No. 2.

Velocity, in feet per second.	Loss of head between *B* and *E*.
1.86	0.1887
3.75	0.5960
5.01	1.1848
6.72	2.0407
8.47	2.8657
9.99	3.9210
11.73	5.4280
14.59	7.6684
.....	.....
.....	.....

Elbow No. 3.

Velocity, in feet per second.	Loss of head between *B* and *E*.
2.72	0.3681
3.77	0.6496
4.90	1.0435
5.06	1.1490
6.72	1.9430
8.77	3.1200
9.96	4.0370
10.99	4.9187
13.53	7.2370
.....	.....

Elbow No. 7.

Velocity, in feet per second.	Loss of head, between *B* and *E*.
14.925	7.7775
12.233	5.3279
10.695	4.2053
8.8675	2.8812
7.565	2.1200
6.590	1.6239
5.525	1.1796
3.600	0.5200
3.000	0.3780
2.195	0.2009

Elbow No. 8.

Velocity, in feet per second.	Loss of head between *B* and *E*.
1.75	0.1512
2.34	0.2476
3.31	0.4785
5.22	1.1258
6.72	1.8214
7.37	2.1516
8.89	3.1102
10.62	4.3664
12.36	5.8523
14.795	8.0186

Elbow No. 9.

Velocity, in feet per second.	Loss of head between *B* and *E*.
1.67	0.1552
2.14	0.2334
3.27	0.5107
4.48	0.6206
6.52	1.8597
7.473	2.3841
8.832	3.3344
10.610	4.7400
12.402	6.3570
14.364	8.4408

Tee.

Velocity, in feet per second.	Loss of head between *B* and *E*.
1.400	0.1348
1.957	0.2446
3.180	0.6236
4.195	1.0368
5.787	1.9041
6.880	2.7099
8.355	3.8200
10.106	5.5910
11.160	6.7250
12.990	9.0580

Mr. Davis.

Mr. Davis.

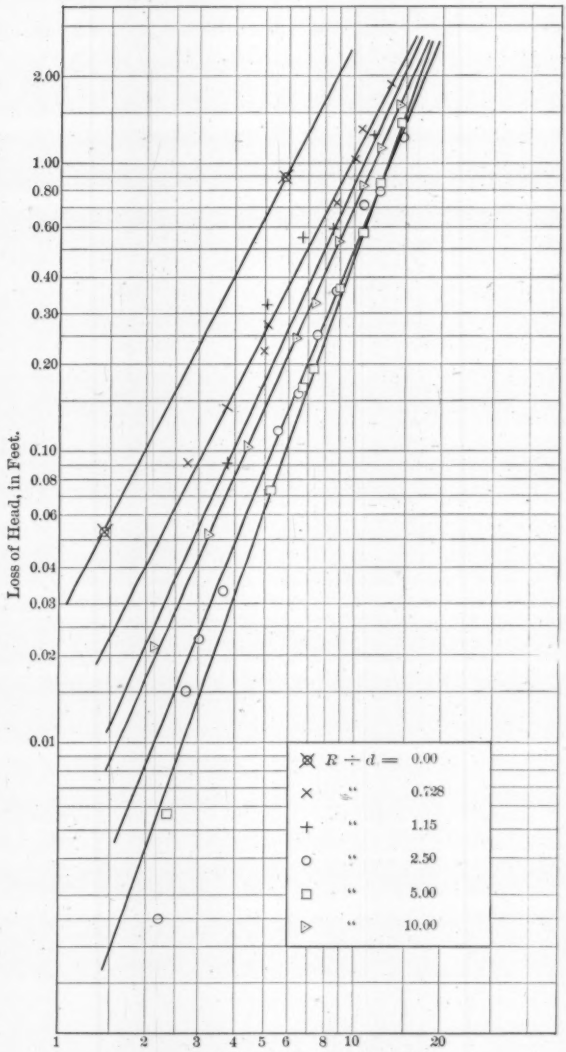


FIG. 17.

Mr Davis. basis of comparison used by the author in Figs. 3 and 4 and the plotting of Mr. Brightmore's experiments in Fig. 13. This case may have a practical bearing in connection with such flexible pipes as fire hose. In this case the desired data were secured by deducting from the total loss of head, as shown by the gauge readings between Piezometers *B* and *E*, such an amount as would be obtained by multiplying the actual center-line length, measured along the curve between *B* and *E*, by the loss of head per foot of straight pipe at the given velocity,

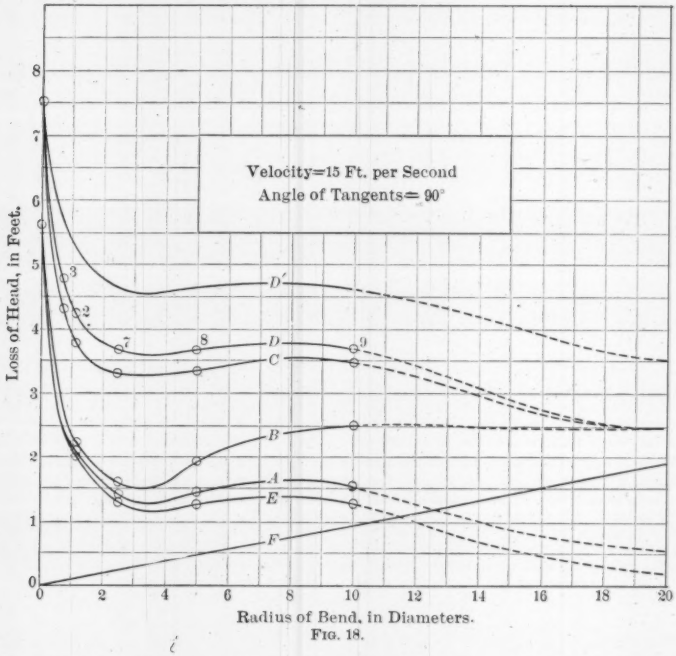


FIG. 18.

as taken from Fig. 15. The results of such computations are plotted on logarithmic cross-section paper in Fig. 17. It will be seen that such a plotting gives a straight line for each pipe curve, at least for velocities greater than 2 ft. per sec. Unfortunately, the lines are not parallel, which indicates that the radius of curvature of the bend, expressed in terms of pipe diameters, has some effect on the exponent of v in a formula of the form

$$H_2 = m\, v^n,$$

where H_2 = the excess loss of head as considered in this case. From Fig. 17, the curves marked *A*, in Figs. 18 and 19, have been prepared

by reading off the values of H_2 where the various lines cross the v lines for $v = 15$ and $v = 5$ ft. per sec. By an inspection of Curve A it will be seen that a right-angled turn, such as a tee, gives a loss of head of 5.6 ft. under a 15-ft. velocity. As the radius of curvature, R, increases from the value 0, given by the tee, the loss of head at the given velocity very rapidly decreases, reaching a minimum when R is approximately equal to four diameters of the pipe. The curve then apparently rises to a maximum at about eight diameters, and then probably drops off again gradually. Unfortunately, the pipes tested did not have the proper radii of curvature to fix absolutely the minimum and maximum points, nor any points beyond $R = 10d$, and the portions of the curves to the right of the latter point have been merely sketched in, in accordance with the writer's estimation of their direction, as based on Mr. Brightmore's curves shown in Fig. 13. Perhaps these curves should rise more, as indicated by the Detroit experiments. Mr. Davis.

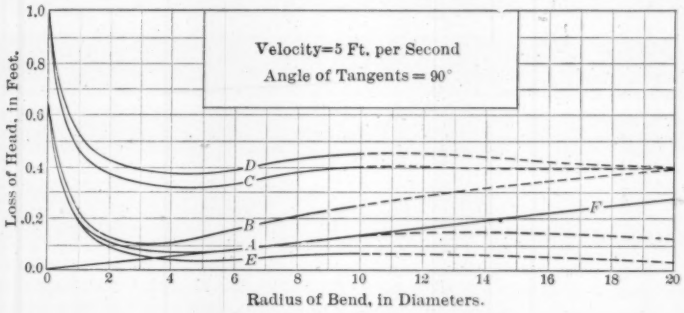


FIG. 19.

Case B.—It may at times be desired to know the loss of head occasioned by a curve in a pipe line, without regard to its length or what effect a variation in its length may have on the total friction loss of the system. It is not possible to measure this loss by piezometers placed at the two extremities of the curve, because a considerable part of the curve loss occurs in the down-stream tangent. A curve discharging into the air at its down-stream extremity will not develop the resistance that it would with a piece of straight pipe beyond; but, by observing the actual loss between two points, as B and E in Fig. 14, and deducting from it the loss normally occurring in a length of straight pipe equal to the length of straight pipe actually existing between B and E, the loss, as defined in this case, will be obtained.

The loss of head for this case is plotted against the velocities on logarithmic cross-section paper in Fig. 20. It will be noted that the lines for the curves of different radii are more nearly parallel than those of Case A. From Fig. 20, the curves marked B, in Figs. 18 and

Mr. Davis. 19, have been prepared in the same manner that Curve *A* was prepared from Fig. 17. It will be remembered, from the definitions, that Curve *B* gives the total loss, while Curve *A* gives only the excess loss over what would occur in an equal length of straight pipe. The vertical intercepts between Curves *A* and *B*, therefore, must be equal to the loss of head in a length of straight pipe equal to the length of the curve. The straight lines, *F*, in Figs. 18 and 19, give the friction loss at the respective velocities of 15 ft. per sec., and 5 ft. per sec. for various lengths of pipe expressed in terms of diameters of pipe. The ordinates to this straight line are equal at all points to the vertical intercepts between Curves *A* and *B*. Curve *B* will never fall below the straight line, *F*, for it does not seem reasonable to suppose that the loss in any curve can be less than the loss in an equal length of straight pipe. If Curve *A* has been drawn too low or too high, beyond the point where $R = 10d$, then Curve *B* is also too high or too low by an equal amount.

This case is mentioned by Professor Schoder as one in which the various curves are introduced between two fixed lengths of pipe. It has not much practical value, but is discussed here because it shows the relation between Curve *A* and the other curves to be described.

Case C.—In this case will be considered the losses occurring in pipes consisting of a straight part and a curve, the total lengths to be the same in all, but the lengths of straight part to vary inversely as the length of curve. The amount of straight pipe to be included must be chosen arbitrarily. The writer has used a length equal to 20 pipe diameters when the length of the curve is zero. Then, when the length of the curve is equal to 20 pipe diameters, the length of straight pipe included will equal zero. Curves *C* on Figs. 18 and 19 were most easily plotted by simply adding to the ordinates of Curve *A* an amount equal to the ordinate of Curve *F* at the $20d$ point. That is, Curve *C* represents the sum of the loss due to friction in 20 diameters of straight pipe, plus the excess loss in the curve, over the loss in an equivalent length of straight pipe. Curve *C* might have been plotted also by adding to the ordinates of Curve *B* the friction loss due to the various lengths of straight pipe required to make the total length of pipe equal 20 diameters. These lengths are given in Table 13.

Case D.—Of more practical importance than any of the cases thus far discussed is the case where two fixed points are to be connected by two straight pipes joined by a 90° curve, and it is desired to know the relative total losses which will occur between the fixed points with different curves. Here it is necessary, arbitrarily, to assume some fixed points. In the computations the writer has chosen points that would lie at the extremities of a curve having a radius of 20 diameters. For this curve there would be no straight pipe, but the loss due to the curve, occurring in the down-stream tangent beyond the point con-

Mr. Davis.

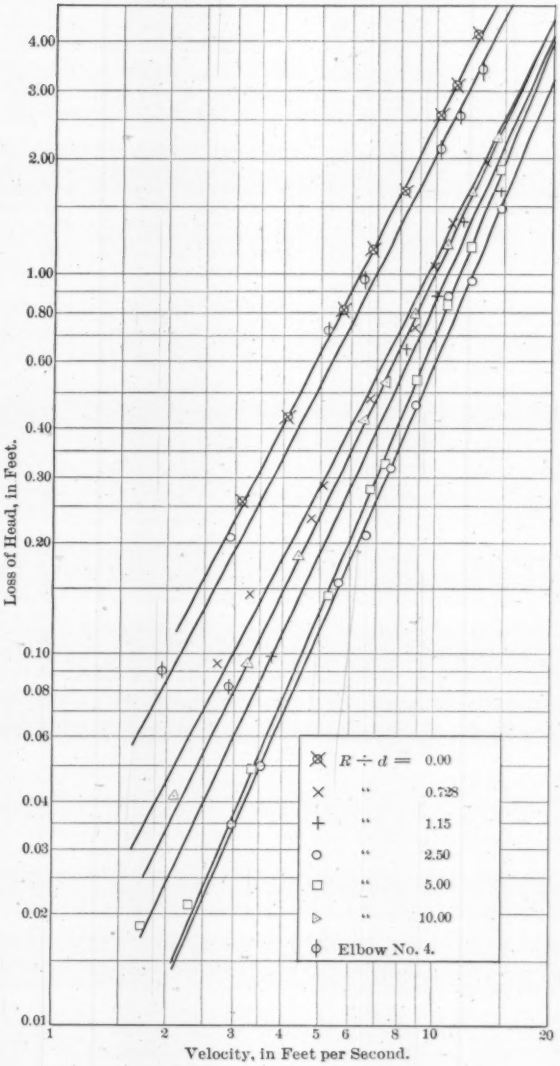


FIG. 20

Mr. Davis.

TABLE 13.—LENGTHS OF CURVE AND STRAIGHT PIPE WHEN THE TOTAL LENGTH = 20 DIAMETERS.

$\frac{R}{d}$	Length of curve, in feet, for a $2\frac{1}{16}$-in. pipe.	Length of straight pipe, in feet.
0.0	0.0	5.41
0.728	0.20	5.21
1.15	0.31	5.10
2.50	0.68	4.73
5.	1.35	4.06
10.	2.71	2.70
20.	5.41	0.0

sidered, has been taken account of. When the radius of curvature is zero, the total length of the two straight pipes would be 6.88 ft. for a $2\frac{1}{16}$-in. pipe. Curve *D* represents the losses for this case. The curve can be constructed by adding to the ordinates of Curve *A* the product of the loss per foot in the straight pipe multiplied by the length of straight pipe required to connect the given points. These lengths are given in Table 14.

TABLE 14.

$\frac{R}{d}$	Length of curve, in feet, for a $2\frac{1}{16}$-in. pipe.	Length of straight pipe, in feet.
0.0	0.00	6.88
0.728	0.20	6.63
1.15	0.31	6.48
2.50	0.68	6.02
5.00	1.35	5.16
10.00	2.71	3.44
20.00	5.41	0.00

Owing to the arbitrarily assumed position of the fixed points, Curve *D* will meet Curves *C* and *B* at the 20*d* ordinate. If some other position of the fixed points had been chosen, it would simply shift Curve *D* an amount depending on the length of additional straight pipe introduced between the fixed points. For example, Curve *D'* has been drawn for the loss of head between two points located so that a 90° turn having a radius of 30 pipe diameters would connect them.

Case E.—None of the curves, *A*, *B*, *C*, or *D*, is very convenient to use in estimating the loss of head in a given pipe system containing bends. Curve *E* has been plotted for more convenient use.

In Fig. 21, let x represent the loss of head which would occur in a length of straight pipe equal to $AB + BC$; let y represent the loss which would occur in a length of straight pipe equal to $DB + BE$, and let z represent the actual loss caused by the curve, DE, as given by Curve *B* on Fig. 18.

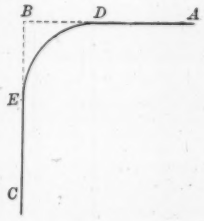


FIG. 21.

Then the actual loss of head occurring between A and C would be given by Mr. Davis.

$$x - y + z.$$

For the case of the tee, y becomes zero. For curves of various radii, x in the above equation remains constant, while y increases with the radius of curvature, and z follows the law illustrated by Curve B of Fig. 18. Since x is a constant for all cases, the points, A and C, can be most conveniently chosen so that $x = 0$. Then Curve E, Fig. 18, can be plotted, using $z - y$ as ordinates. The distance, DBE, is equal to 1.27 times the length of the curve, hence it is likely that, for bends of large radius, the loss, y, may be greater than the loss, z, and Curve E may then have negative ordinates. This Curve E corresponds to the author's curves in his Figs. 5 and 6.

To estimate the total loss of head in a pipe system, therefore, one should compute the loss in the straight pipe as though it ran directly to the point of intersection of the tangents and to this loss add the loss given by Curve E for the particular bend to be used. Of course, an E curve must be computed for each velocity. The data for Curve E, for a velocity of 15 ft. per sec., are given in Table 15.

TABLE 15.

$\frac{R}{d}$	Length of tangents, DBE.	Loss in curve.	Loss in tangents.	Net loss.
0.0	0.0	5.6	0.0	5.60
0.728	0.25	2.5	0.09	2.41
1.15	0.396	2.2	0.15	2.05
2.50	0.83	1.6	0.3	1.30
5.00	1.72	1.9	0.63	1.27
10.00	3.44	2.5	1.20	1.30

The Effect of Pipe Diameter.

In Fig. 22 a comparison is made of the loss of head occasioned in pipes of different sizes by curves having a ratio of $R \div d$ equal to 4, in all cases, for velocities of 5 ft. per sec, and 10 ft. per sec. Points A are taken from Curves A in Figs. 18 and 19. Points B and C are from the author's plotting of Mr. Brightmore's work in Fig. 13. Points D are from the author's curves in Fig. 4. Point E is from Table 36 of the Detroit experiments.* These points seem to indicate that, for a radius of curve equal to 4 pipe diameters, the loss of head is independent of the size of pipe. An inspection of the data seems to indicate that the law holds for other ratios of R to d. Point D, it will be noted, is based on the author's first straight-pipe experiments. Point

* *Transactions*, Am. Soc. C. E., Vol. XLVII, p. 181.

Mr. Davis. F is based on his second straight-pipe experiments. The fact that it does not lie on the line for a velocity of 10 ft. per sec., where it belongs, leads the writer to think that the author's second straight-pipe experiments should not be used, but that the first experiments give reliable results.

Magnitude of Losses.

The author has given an indication of the magnitude of the losses by computing the lengths of straight pipe giving losses equal to those caused by the various curves at different velocities. The writer wishes to show the actual horse-power consumed in pumping water against the curve resistance. The horse-power may be obtained by using the formula

$$h\,p = \frac{H_E \times v \times A \times 62.5}{550}$$

in which H_E = the head lost, as given by the methods of Case E,
v = the mean velocity, in feet per second,
A = the area of cross-section of the pipe, in square feet.

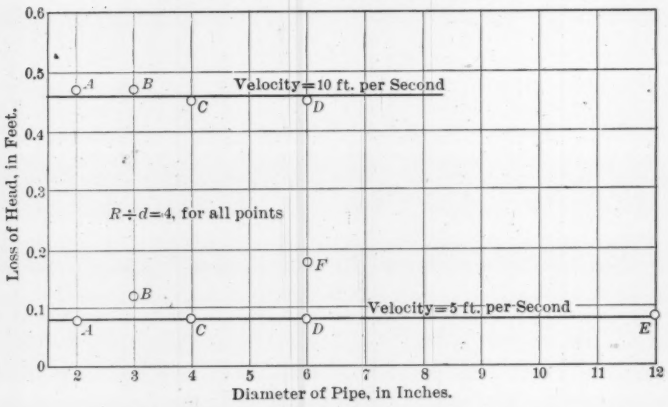


Fig. 22.

By this formula, curves were plotted for the 2-in. pipe of these experiments. The total horse-power lost, due to a bend in a pipe of this size, is necessarily small, owing to the small weights of water discharged. The writer, therefore, has made use of his assumption that the loss of head is independent of the size of pipe, and has enlarged the horse-power scale to give the losses in a 12-in. pipe, by simply multiplying by $\frac{12 \times 12}{2 \times 2}$, since the weight discharged is proportional to the square of the diameter of the pipe. Therefore, Fig. 23, prepared in this way, may be used for any size of pipe by constructing a suitable horse-power scale.

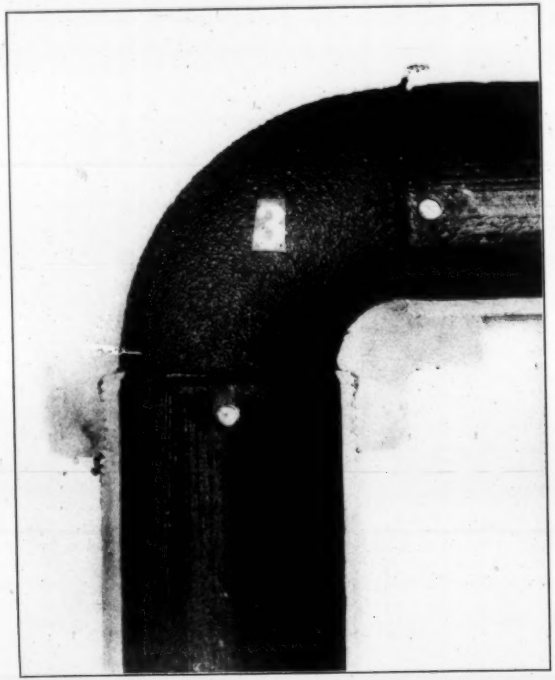


FIG. 1.—INTERIOR OF CAST-IRON "DRAINAGE" ELBOW, NO. 3.

FIG. 2.—INTERIOR OF CAST-IRON "SHORT TURN" ELBOW, NO. 4.

Mr. Davis

It is the writer's intention, at the first opportunity, to continue the experiments on the 2-in. pipe, in an attempt to fix more definitely the direction of the curves for bends of long radius, and the results of the further study will constitute the basis of a Bulletin to be published by the University of Wisconsin.

The Effect of Enlargements.

Referring to Table 11, it will be seen that Curves 2, 3, 7, 8, and 9 had the same internal diameter as the pipe, while the others were slightly larger. In the foregoing discussion only the curves having

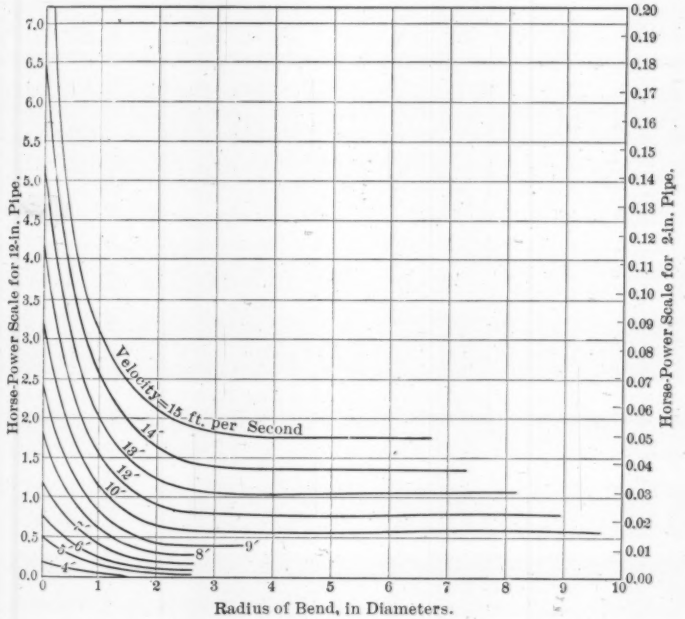


Fig. 23.

the same diameter as the pipe have been considered. The points on Curve *B*, Fig. 18, have been numbered to correspond with the numbers of the elbows. It was found that Elbow No. 1 gave the same loss of head as Elbow No. 3. The increase in loss to be expected in Elbow No. 1, due to the slight enlargement and contraction of section, seems to have been exactly balanced by the reduction in loss due to a slightly longer radius of curvature.

Mr. Davis. An idea of the increase in loss due to the enlargement from $2\frac{1}{16}$ in. to $2\frac{3}{8}$ in. and again contracting to the smaller size may be had by comparing Elbows Nos. 3 and 4 which are both of cast iron, of about the same degree of roughness, as may be seen in Figs. 1 and 2, Plate V, and both have a radius at the center line of 0.728 diameter. The pieces of pipe shown riveted to the sections of the elbows are not the pipes used in the experiments, but were inserted merely to show the actual distance that the pipes were screwed into the elbows. The pipes used in the experiment were used full length and had no burr at the end, like those shown, which was caused by hand cutting.

On the basis of Case *B*, the loss of head for Elbow No. 3 is given by

$$H_3 = 0.0113v^2,$$

and the loss of head for Elbow No. 4 is given by

$$H_4 = 0.0202v^2.$$

The loss in Elbow No. 4, therefore, is about 1.8 times the loss in Elbow No. 3.

Elbow No. 5 gave about the same loss as Elbow No. 2.

Mr. Schoder. ERNEST W. SCHODER, ASSOC. M. AM. SOC. C. E. (by letter).—The studies of Mr. Davis make valuable additions to our knowledge. His plotting (Fig. 22), showing the effect of pipe diameter with $\frac{R}{d} = 4$, indicates that law and order exist. Further investigations in this interesting field will doubtless give closer definition to the present vague outlines of the laws of curve resistance.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1094

THE SINKING OF THE PIERS FOR THE GRAND TRUNK PACIFIC BRIDGE AT FORT WILLIAM, ONTARIO, CANADA.*

By H. L. Wiley, Jun. Am. Soc. C. E.

With Discussion by Messrs. C. R. Fickes, George B. Francis and Robert A. Marshall, F. W. Skinner, and H. L. Wiley.

This paper outlines the construction methods used in sinking the piers for the Grand Trunk Pacific Railway Bridge, crossing the Kaministiquia River, at Fort William, Ontario, Canada.

The proposed terminals of the Grand Trunk Pacific at the head of Lake Superior are separated from the main line by the Kaministiquia River. At the bridge site the river has a maximum depth of about 20 ft. at low water, being at that stage 325 ft. in width. The north bank of the river, to which the draw span of the bridge swings, is steep, and rises to a height of about 35 ft. above water. The south bank is low, sloping from the river at a grade of 1 : 10.

Test borings, taken at the bridge site during the winter of 1906-07 by the railway engineers, showed a stratum of firm blue clay, about 35 ft. thick, covering a layer of water-bearing gravel varying in thickness from 3 to 7 ft. The water contained in this gravel was under sufficient pressure to maintain a steady flow through several of the abandoned test holes, and, when confined, it rose to an elevation 4 or 5 ft. above

* Presented at the meeting of September 16th, 1908.

the river level. This gravel is underlaid with bed-rock, from 57 to 60 ft. below the water surface. The rock surface is comparatively level, dipping to the north about 2 degrees.

The plans prepared by the railway showed only the general design of the two piers, the details and construction methods being left for field decision. The pivot pier consists of a steel shell, 31 ft. in diameter, sunk to bed-rock and filled with concrete. The south pier is composed of two smaller shells, set side by side. These are 15 ft. in diameter, and 18 ft. apart from center to center.

SKETCH SHOWING FOUNDATIONS
G. T. P. BRIDGE,
FORT WILLIAM, CANADA

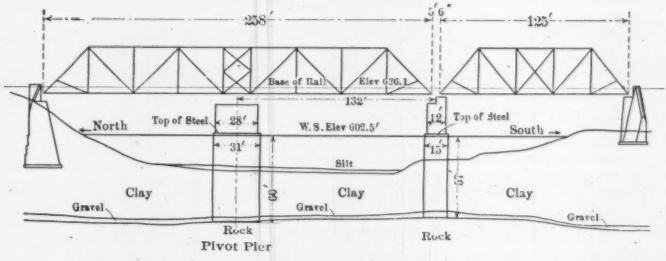


FIG. 1.

The plans called for ½-in. plate, single-riveted on the horizontal seams, and double-riveted on the vertical seams, and ¾-in. rivets with round heads. The contract for the work having been let in the latter part of August, 1907, an interval of about 3 months remained before severe cold weather would set in, closing navigation and rendering all outside work more costly. Therefore operations were begun immediately.

For the falsework at the pivot pier, two rings of piling were driven about the center of the pier, the diameter of the inner ring being 37 ft., and of the outer one 54 ft. These piles were cut off and capped 8 ft. above the water. The caps were of 12 by 12-in. fir timber, radial from the center of the pier, and overhanging the perimeter of the steel shell 2 ft. There were twenty piles in each ring. These were cross-braced and tied securely, making the structure as rigid as possible, to lessen any movement that might be caused by the current, which

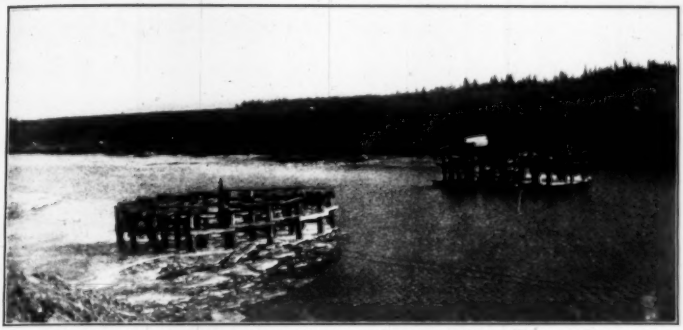


FIG. 1.—GRAND TRUNK PACIFIC RAILROAD BRIDGE AT FORT WILLIAM, ONT. PILING AT PIVOT PIER CUT OFF AND CAPPED.

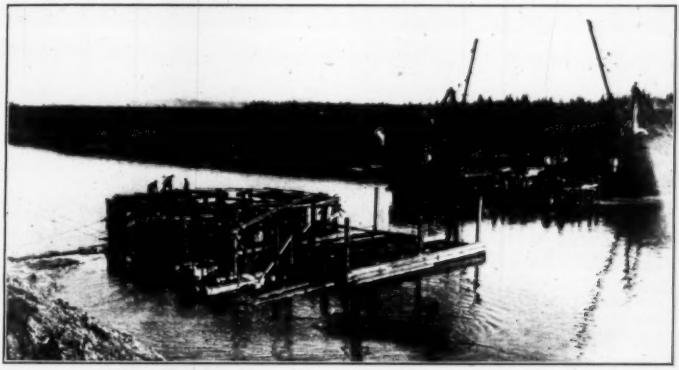


FIG. 2.—SINKING FENDER CRIB UP STREAM FROM PIVOT PIER.

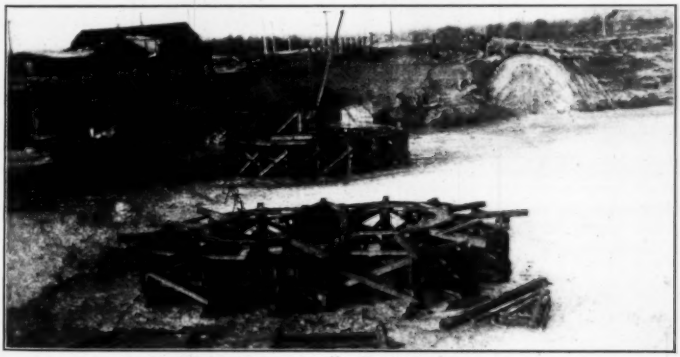


FIG. 3.—FALSEWORK OF PIERS COMPLETED.

varied from 3 to 6 miles per hour. The piles were driven to gravel, to prevent settlement in the finished falsework. The structure was then decked and a circular track built upon it. This track was for a small derrick car, the purpose of which was to pick up the plates forming the shell, carry them to place, and hold them in position while being bolted up ready for riveting.

A slot, 2 by 8 in., was cut through the caps where their center lines intersected the perimeter of the steel shell, and a casting, through which "hanger rods" worked, was set on each cap. The hanger rods were for holding a course of plates during riveting, supporting the finished shell until the river bottom was reached, and for controlling the movements of the shell until it rested on bed-rock. The rods were 8 ft. long, of 1½-in. steel, threaded, and an eye of Swede iron was welded to the lower end of each. Hook-plates, hung in these eyes, connected the hanger rods and the plates forming the shell. There were two hanger rods at each cap, 4 in. from center to center, one outside of the shell, and one within it. The hook-plates covered four rivet holes, and were bolted to the steel plates while the derrick car held them suspended, the weight of the plates being transferred to the hanger rods by slacking the chain blocks with which the derrick car was rigged.

The plates were of ½-in. steel, 10 ft. long and 5 ft. wide; they were curved to a radius of 15½ ft., and weighed about 1 100 lb. each. There were 130 plates in the shell, 13 vertical courses of 10 plates each. The time required to swing the plates for one course from the storage yard to the derrick car, and to bolt them up ready for riveting, averaged about 2½ hours, or 15 min. for each plate. Five courses were riveted up when the shell touched bottom. The weight of the shell caused it to penetrate the bottom to an average depth of 1 ft. A 2-in. water-jet was then rigged from a single-cylinder, 6-in., steam, force pump, and by this means the material at the cutting edge was disturbed sufficiently to permit a further settlement amounting to about 1 ft.

Each outside hanger rod was then carried back to the pile carrying the cap from which the rod was suspended, and bolted to the pile, thus tying the inner end of the cap in place. Jacks were placed under each cap, resting on the edge of the shell, and the combined action of the water-jet and twenty jacks forced the shell about 5 ft. farther into the bottom, the total penetration being at this time 7 ft.

The shell was then pumped out. As the water was removed, a course of bracing was placed at each horizontal seam of the shell. This bracing was of 12 by 12-in. hemlock, four timbers being set in the form of a square. Two squares were placed together, one being turned 45° about the center of the pier, thus forming a star-shaped set of bracing, giving eight points of support to the sides of the shell, and leaving an octagonal central opening about 18 ft. across.

Five days after the shell was cleared of water, the material under the cutting edge gave way, and the shell filled, the blow being confined to about 4 ft. of the perimeter. This hole was carefully filled, and the shell was pumped out again, only to blow out, about 5 hours later, at a different point.

At this time a flow of water within the shell was noticed, coming apparently from one of the holes left by the test borings, and being approximately equivalent to the flow from a 4-in. pipe. It was evident that there would be great difficulty in keeping the shell cleared of water, and an attempt was made to sink it still farther into the river bed. It was loaded with 175 tons of steel rails, the jacks were placed in position as before, and it was forced downward another 5 ft., the total penetration then being 12 ft. Another attempt to clear the shell of water, resulting in failure, indicated that the flow from the gravel had destroyed the integrity of the material within the shell. This method was abandoned and the work proceeded as follows:

The overhanging caps were cut off, and two more courses of steel were riveted up. Timbers were placed across the top of the shell, and a tight floor, about 1 ft. from water level, was hung from these timbers, within the shell. A form was built, following the octagonal outline of the inner opening left by the timber bracing, and concrete was deposited between this form and the steel shell. Meanwhile, a derrick was erected on a fender crib which had been sunk immediately up stream from the pivot pier, and excavation was commenced within the shell, using an orange-peel bucket. The settlement of the shell was constant from this point, and, as it sank, the ring of concrete was carried upward, thus forming a steel-protected pipe or drum, having an outside diameter of 31 ft., the inner opening being octagonal.

When the shell finally reached rock, the surface of the rock was cleaned, and a layer of concrete about 7 ft. in thickness was deposited under water, which sealed the flow from the water-bearing gravel and

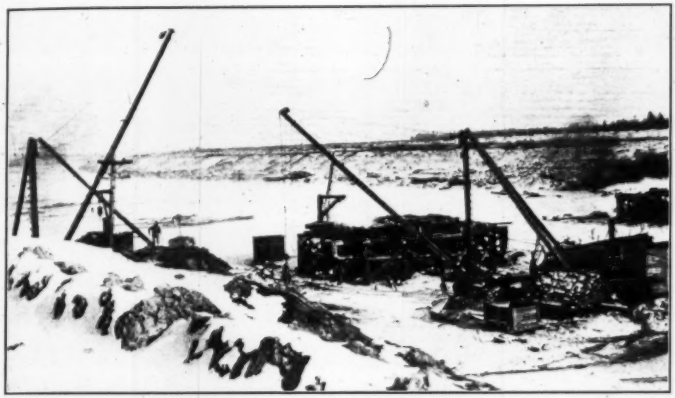


FIG. 1.—PIVOT PIER AND DERRICK.

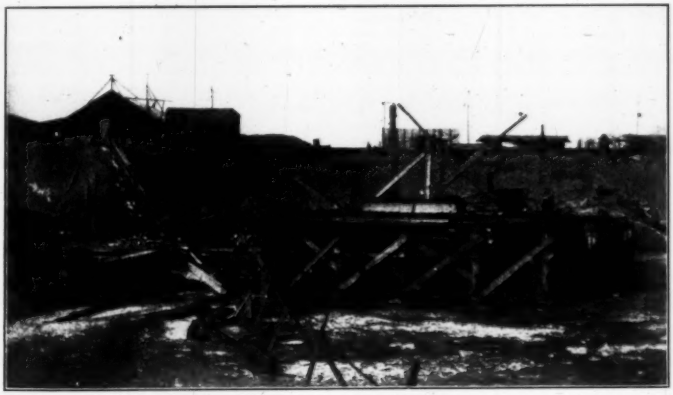


FIG. 2.—FALSEWORK AND DERRICK CAR, PIVOT PIER.

allowed the removal of the bracing. When the timber was removed, the interior opening was filled with concrete, forms were built at the water level, and the pier was carried up to its final elevation.

The concrete used was a 1:3:5 mixture, the gravel and sand being brought in by train from a point thirty miles distant on the line of the Grand Trunk Pacific. This material was clean, and in its natural state closely approximated the required proportions. Tests were made from time to time to determine its condition, and enough sand was added to make it comply with the specifications. Screening was considered unnecessary. To prevent the concrete from freezing, the sand and gravel were heated. Three heaters, made from sections of 36-in. cast-iron pipe, were placed near the stock piles. Wood for heating purposes was plentiful, and the cost of heating all material averaged about $1.00 per cubic yard of concrete. The materials were conveyed to the mixer by cars, and the concrete was swung to the derrick on the fender crib by using a second derrick located on the river bank. After the ice formed, the derricks exchanged boxes on the ice, and the mixer, running constantly, kept one batch of concrete moving at all times. The batches averaged 22 cu. ft., the average output being 11 cu. yd. per hour.

In the concrete, pieces of stone, containing from 2 to 15 cu. ft., were placed by the derrick on the fender crib. These stones were heated by immersing them in a tank of hot water for a few minutes, the volume being indicated by a displacement scale marked off inside the tank. In this way a check on the total volume of material was obtained, the combined volumes of stone and concrete equaling the quantity indicated from measurements made inside the shell. The total quantity of stone and concrete in this pier is 2 200 cu. yd.

Conditions at the smaller pier on the south side of the river were somewhat different, the water being only 17 ft. deep, and bed-rock 57 ft. from the water surface.

This pier consists of two concrete-filled steel shells, 15 ft. in diameter, set side by side at right angles to the center line of the bridge, with a space of 3 ft. between them. Falsework, similar to that at the pivot pier, was erected. To handle the steel plates, a derrick was placed on the center line of the bridge, resting on three small cribs sunk for the purpose.

The shells were lined with concrete as they sank, and, owing to the

fact that they could be pumped out, about two-thirds of the total excavation was completed in the dry, the derrick disposing of the material as it was excavated. The shells were in no way connected, but were carried down with as nearly the same amount of progress as possible. The general progress was in jumps of from 2 to 5 ft. The steel was carried high enough at all times to prevent any chance of the shell disappearing beneath the surface. The progress could be closely controlled by the amount of excavation. The shells were brought to place finally with a difference in elevation of less than ½ in. Along the center line of the bridge, they were about 4 in. out of position. This was corrected when the forms were built at the water line, where a slight offset had been provided for such a contingency.

There are 1 055 cu. yd. of concrete in this pier, the same mixture, 1:3:5, being used as in the pivot pier. The two shells were joined at the top by a reinforced concrete beam. The sand and gravel for this pier had been placed on the south bank of the river before the close of navigation. This material was dredged from the bed of Lake Superior during the summer, and was used without screening. The mixing plant for this pier was located on the south bank, and the concrete was conveyed to the derrick by cars running on a track laid on the ice.

It was thought that difficulty might arise from the shrinkage of the concrete inside the shell, with a consequent destruction of the bond between it and the steel, and, to prevent this, the first course of concrete was allowed to set under water, where some expansion would occur. The concrete in the piers was kept warm, where exposed to the air, by covering the piers and turning live steam into the enclosed space. The concrete below the ice line, and under water, was, of course, in no danger from freezing.

The steel shells were rendered water-tight by caulking them at the laps, and by driving a small triangular wedge at the scarfs. The resistance of the material through which the shells were sunk was found to vary from 275 to 320 lb. per sq. ft. This is the net skin friction, after deducting the resistance caused by the cutting edge, the laps in the plates, and the rivet heads.

The cutting edges were reinforced by riveting, to the lower course of steel, an additional ½-in. plate, 3 ft. wide. This was considered sufficient, as the test borings had shown the material to be clear, and free from sunken trees or boulders.

FIG. 1.—INTERIOR OF SHELL OF PIVOT PIER, SHOWING BRACING.

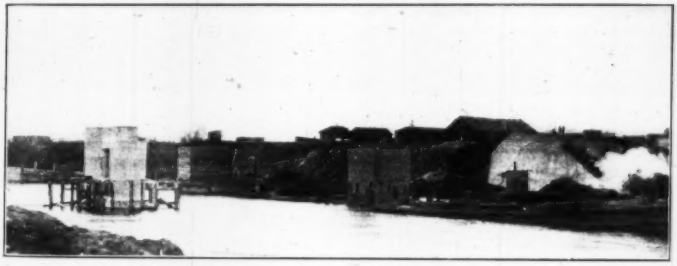


FIG. 2.—COMPLETED PIERS, LOOKING UP STREAM FROM THE SOUTH BANK.

The riveting and caulking were done with air, the compressor being of the locomotive type. Owing to the atmospheric moisture, the air line and hammers at times gave some trouble, due to the intense cold.

The plates for the shells were punched and bent at Chicago and shipped ready for erection. They were fitted up easily and rapidly, as the work of bending and punching had been done well and carefully.

Work was carried on as rapidly as possible, three shifts being employed on the concrete at times. The total time consumed in this work, disregarding lapses and minor delays, was about 5 months. The cost of the two piers was about $60 000.

The work came under the supervision of Mr. George A. Knowlton, Division Engineer in charge of the Lake Superior Branch of the Grand Trunk Pacific Railway. The writer designed the lay-out of the plant and the method of construction, and was in charge of the work.

DISCUSSION

Mr. Fickes. C. R. FICKES, M. AM. SOC. C. E. (by letter).—This paper is of especial interest to the writer, who recently completed the deep foundation work for a bridge over Red River near Shreveport, La., for the St. Louis Southwestern Railway Company.

The weather conditions were not so frigid as those described by Mr. Wiley, but such conditions would have been welcomed in view of a yellow fever epidemic that occurred during the construction of the bridge.

Seven piers and one abutment were founded by the open-caisson method. Four of these, including the pivot pier, were carried down to solid rock, while the others were built on piles driven under water by a long follower.

The method of founding the pivot pier may be of interest.

This pier was in the channel of the stream, which had a velocity of about 4 miles per hour at ordinary stages of the water and 8 miles at high-water stages. There is a variation of about 40 ft. between extreme high- and low-water stages, and the tropical rains of that region often bring on a rise of 20 ft. or more in 12 hours.

Borings previously taken at the site of this pier showed that the rock was about 90 ft. below the ordinary stage of the water, and was overlaid by a stratum of stiff blue clay 20 ft. thick. Above this, up to the bed of the stream, the borings showed alternate layers of clay, gravel, and coarse sand for a thickness of 40 ft. This made about 65 ft. of soil to be penetrated by the caisson.

The coffer-dam was octagonal in shape, being 37 ft. on the short diameter. It was built of heavy timbers of yellow pine varying in size from 12 by 12 in. in the bottom courses to 8 by 12 in. at the top of the crib. These timbers were fastened together by $\frac{7}{8}$-in. drift-bolts, 4 ft. apart in each course, and the crib was braced inside by 6 by 12-in. sticks joining the centers of alternate sides of the octagon. These braces were from 4 to 6 ft. apart vertically and also served as supports for a cylindrical movable form to be described later.

The cutting edge of the caisson was formed of $\frac{3}{8}$-in. plates, 30 in. wide, joined at the corners with 4 by 4-in. angles and well riveted. The cutting edge was fastened to the bottom courses of the timbers with heavy iron straps and $\frac{7}{8}$-in. bolts.

All joints between timbers were carefully caulked with oakum before being lowered beneath the water.

Vertical sheeting of 2 by 12-in. surfaced planking was spiked on the outside of the crib to lessen the friction.

The caisson was built on a platform supported by piling driven circular around the site of the pier, and lowered to the bed of the stream by eight lowering screws 3 in. in diameter and 30 ft. long.

Inside this octagonal caisson, and concentric with it, was supported a cylindrical movable form 25 ft. in diameter, made of 2 by 6-in. by 12-ft. lagging, smooth on the outside of the cylinder and well braced inside. This left a space about 5 ft. wide between the form and the inside of the caisson, which was filled with concrete as the caisson was lowered. The form was raised as soon as the concrete hardened, and was not allowed to become submerged in the water. Mr. Fickes.

This wall of concrete gave the requisite strength to withstand the pressure when the crib was pumped out, and also the necessary weight to overcome friction in sinking.

This concrete shell was carried up 65 ft. from the cutting edge, so that the top of it would correspond with the bed of the stream, when the cutting edge had reached the rock.

When the caisson had been lowered to the bed of the stream, the material inside was removed by two 1-yd. orange-peel dredges operated by derricks and hoisting engines mounted on a large floating barge anchored beside the crib. Other barges carrying the concrete mixer and material were anchored on the opposite side of the crib, and the operations of building up the concrete and timber wall and of excavating and sinking the crib went on alternately.

It was found that the weight of the wall was sufficient to carry the crib down to the required depth and no additional loading was necessary.

Occasionally, when the excavation had been carried down 3 or 4 ft. below the cutting edge and the crib failed to follow, a small charge of about half a stick of dynamite, dropped into the hole and exploded, caused the crib to settle at once. Several logs were encountered by the cutting edge. These were broken up by dynamite placed by divers and exploded by an electric battery.

No trouble was had at any time from material running in from the outside under the cutting edge.

Only one mishap occurred during the construction of this pier, and that happened when the cutting edge lacked only a few feet of reaching the rock. The top of the concrete wall was then about 3 ft. above the bed of the stream, and above this was about 25 ft. of timber crib extending a few feet above the water. A sudden rise in the river brought down several acres of driftwood, carrying away four clusters of protection piles which had been driven up stream from the pier, and finally breaking off and carrying away that part of the crib above the concrete wall. All barges and floating equipment were torn loose from their anchorages and only recovered with much difficulty several miles down stream.

The problem now was to replace the lost part of the crib and attach it to that portion left intact under about 20 ft. of water. This was accomplished as follows:

Mr. Fickes.

A new crib of the same shape as the old, but 2 ft. less in diameter, was built and floated into position over the submerged portion, and, by means of weights, sunk so that its lower edge rested on the concrete wall just inside the old timber part of the crib. On the lower edge of this new crib was placed a pad of felt, 2 in. thick, for the purpose of partially caulking the joint. The new crib was securely fastened to the old one by ⅞-in. straps and spikes driven by divers who also completed the caulking of the joint.

When this was accomplished, the excavation of material from the inside of the crib was continued by the dredges, and the cutting edge was soon lowered to the rock.

Divers were then sent down inside the caisson, and the surface of the rock, which was found to be fairly level, was cleaned off as thoroughly as possible by water jets. A hydraulic sand pump was also used for removing the material stirred up by the jets.

A layer of 1:2:4 concrete, 4 ft. thick, was then deposited over the surface of the rock by bottom-dump buckets carefully lowered through the water. This concrete was placed without any interruption so that there would be no joint. Forty-eight hours was given for this concrete to harden, after which two 8-in. pulsometer pumps were lowered into the hole, and unwatered the caisson in a few hours. The bottom was found to be sealed effectually by the layer of concrete already described, and the shell of concrete was practically water-proof. Some little leakage occurred at the joint between the old and new parts of the crib, but this was soon overcome by caulking.

After this, the concreting proceeded rapidly in the dry, and the well was soon filled up to the point where the neat work was to begin. The forms were then erected and the pier carried to completion without mishap.

The average daily distance of sinking the caisson was about 4 ft., and the greatest distance sunk in ten consecutive hours was 8 ft. This is exclusive of time lost by reason of high water and replacing the crib as described.

The completed pier is 26 ft. in diameter above the water, and contains approximately 3 000 cu. yd. of concrete. It is the support for a 300-ft. single-track railway swing span.

The cost of the completed foundation was much less than the average cost of pneumatic work, and has several advantages not possessed by the latter, among which is the fact that the continuity of the concrete is not broken by a deck of timber as is the case with pneumatic foundations.

No trouble was experienced in keeping the caisson in position during the sinking. By careful work with the dredges, the crib was kept practically level at all times. When finally landed, it was less than 2 in. off center in either direction.

Mr. Fickes.

The other caissons sunk by this method were rectangular, 40 by 22 ft., and had concrete walls inside the timber cribs, 4 ft. thick, with a cross-wall of concrete dividing the inside into two wells 12 ft. square, through which the earth was excavated as from the single well of the octagonal caisson.

No trouble was experienced with any of these caissons, as no sudden rise occurred in the river during their construction and sinking.

In the case of one pier erected on shore, the caisson was carried 85 ft. through the soil. Weight in addition to that of the concrete wall was necessary in this case, and was secured by loading the crib with large boxes filled with earth removed by the dredges from the inside of the crib.

The completed bridge consists of four through spans of 200 ft. each, one of 150 ft., and a swing span of 300 ft. There are about 100 ft. of creosoted pile and steel trestle approaches at each end of the bridge.

J. W. Schaub, M. Am. Soc. C. E., was Consulting Engineer for the work, and prepared the plans. M. L. Lynch, M. Am. Soc. C. E., is Chief Engineer of the St. Louis Southwestern Railway. The contract for foundations and steel erection was held by the Missouri Valley Bridge and Iron Company, the steel being fabricated by the Phœnix Company. The writer had direct charge of the work as Resident Engineer from start to completion.

Messrs. Francis and Marshall.

GEORGE B. FRANCIS and ROBERT A. MARSHALL, MEMBERS, AM. SOC. C. E. (by letter).—The description of this foundation work possesses more than usual interest from the fact that it is a successful execution at or near the extreme depth below water at which open coffer-dam work is practicable. From general observation of such work, no case comes to mind where such depths have been reached by open coffer-dam, either in open water or through strata beneath such a depth of water. The common limit for such work is 50 ft. or less; beyond that depth pneumatic caisson methods are usually adopted. The question might be asked why the open method was selected in preference to the pneumatic, or why a pile foundation was not used.

The description has also proved very interesting from the fact that recently the writers were called on to design a method of sinking or placing piers, at quite similar depths, in the Ohio River. Two methods were outlined, which, although not used, may nevertheless prove interesting.

In the study on these designs the writers found two recent instances —one, the Pyrmont Bridge, at Sydney, Australia, the other at Bristol, England—of the founding of similar piers in deep water, which have been fully described.*

* *Minutes of Proceedings*, Inst. C. E., Vol. CLXX, Dec., 1907.

Messrs. Francis and Marshall.

A comparison of the case described in the paper with the Ohio River designs, the Sydney Bridge and the Bristol Bridge, taking typical piers, would be as given in Table 1:

TABLE 1.

Name.	Size of pier, in feet.	Depth of base below highest water, in feet.	Depth of base below bed of stream, in feet.	Base rests on:	Material of pier.	Method.
Fort William Bridge	31, diam.	60	± 40	Rock.	Concrete in steel shell.	Steel shell sunk and pumped out.
Ohio River Bridge..	35 by 80	48	± 36	Rock.	Concrete and stone.	Steel sheet-piling, and pumped out.
Sydney Bridge.....	42, diam.	60	± 36	Rock.	Concrete in steel shell.	Wrought-iron shell sunk and pumped out.
Bristol Bridge.....	43 by 37	45	± 17	Marl.	Concrete and stone.	Timber sheath-pile coffer-dam.

Proposed Methods of Placing the Piers for the Ohio River Bridge.—The proposed bridge was designed to have three piers of an average size of 35 by 80 ft., founded on rock about 36 ft. below the river bottom, with a depth of water ranging from about 1 ft. at extreme low water to about 41 ft. at record flood level.

On account of the magnitude of the work, the time required for construction would necessarily extend through the seasons productive of the maximum variation of depth of water.

The flood records in the Pittsburg office of the Weather Bureau were examined and plotted, and it was found that while the record flood of 1907 rose 41 ft. above low-water level, the rise and subsidence of water was rapid and the majority of the peaks were not more than 10 ft. above low-water level.

A coffer-dam high enough to keep out the record flood of 1907 would be impracticable. It was found that a coffer-dam high enough to keep out an 11-ft. rise of water would permit work on the foundations about 330 days per year, and give practically no interruptions from high water between April 15th and December 1st.

The two principal requirements of construction were that the rock should be uncovered for inspection and then leveled or stepped; and that the concrete foundation should be a solid monolithic mass under the entire pier.

The first requirement made it impossible to deposit concrete under water, as was done in the Fort William Bridge; the second required the protective works to be entirely outside the lines of the pier.

The first plan consisted of the use of a timber crib, the bottom section of which would be built ashore, launched, and towed to the site,

Messrs. Francis and Marshall.

which, in the meantime, was to be partially dredged. The crib, after being securely moored, was to be sunk by loading with material dredged from the river bottom. It was designed with a V-shaped bottom, and the sinking was to be continued by dredging the interior, building up the sides, and continuing the loading until it rested on rock. In construction, the crib was to be made of squared timbers, laid in cob-house fashion, and thoroughly braced and fastened with dock spikes. The outside and inside were to be covered with tongued and grooved sheathing well driven up, which would give better protection than two lines of sheet-piling, without any of the irregularities from obstacles frequently encountered in driving. The interior was then to be pumped out, and cross-bracing between the sides added as the water was lowered. Should unevenness in the rock surface cause a blow or serious leak, it was proposed to stop it by driving outside sheet-piling at the point where needed.

OHIO RIVER BRIDGE
DESIGN FOR CRIB COFFER-DAM

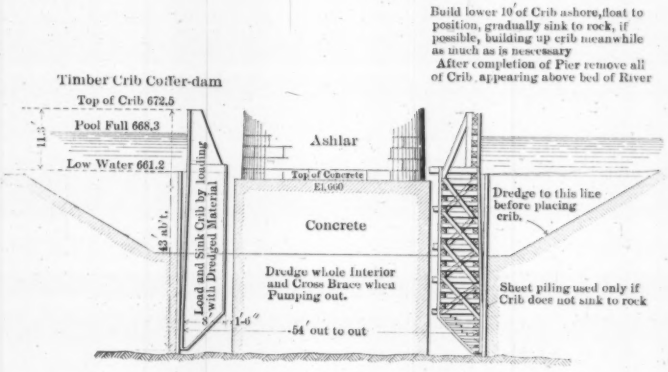


FIG. 2.

After cleaning and leveling the bottom, concreting was to commence, and the cross-bracing was to be removed as fast as the concrete was placed.

As an alternative to the method outlined above, a coffer-dam made of interlocking steel sheet-piling was considered, as it is possible to drive such piling to rock at all points and thus have a tighter job around the bottom, than is the case with a crib which must necessarily stop at the highest point of rock.

The material at the site consisted generally of compact sand and gravel, and, by partial dredging, the cost of driving could be materially reduced.

Messrs. Francis and Marshall.

The progress, as outlined, consisted of dredging to a depth of 15 to 20 ft., driving and bracing the necessary guide piles which would also support the working platform in a manner similar to that used in the Fort William Bridge piers; then driving to rock a single line of interlocking steel sheet-piling weighing 45 lb. per sq. ft. The coffer-dam would then be pumped out, the sheathing being securely braced as the water was lowered. The remaining material inside the coffer-dam would be dredged to rock and concreting commenced, the interior bracing being removed in advance of the concrete.

When the pier was completed to the top of the coffer-dam, the sheet-piling would be pulled and used again on the next pier.

After careful consideration of both methods, it was decided to recommend the use of the steel sheet-piling, the estimates prepared showing it to possess a larger element of economy than the crib construction.

OHIO RIVER BRIDGE
ALTERNATE DESIGN FOR COFFER-DAM

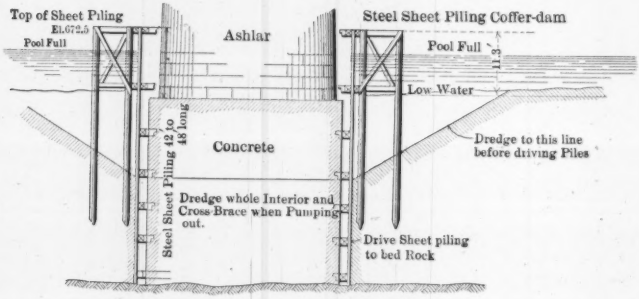


FIG. 3.

The manufacture of steel sheet-piling is of comparatively recent development, and it possesses advantages in foundation construction which, heretofore, were not available.

Method of Placing a Typical Pier for the Sydney Bridge.—The caisson, which formed a part of the pier as well as a coffer-dam, was a double wrought-iron shell with an external diameter of 42 ft., an internal diameter of 32 ft., and a total height of about 53 ft., the shells being concentric and brought together at the bottom to form a cutting edge at the line of the outer diameter. This caisson was sunk to the river bed, then loaded with concrete and, while the interior was being dredged out, the caisson was sunk to bed-rock.

The water was then pumped out, but a blow-out occurred which necessitated the excavation for the leveling off of the irregular rock

Messrs. Francis and Marshall.

surface by the aid of divers, with the caisson full of water. Some of the concrete in the base, around the outer margin of the circle, was placed by divers. After this no trouble was experienced in pumping out the caisson, and the remainder of the work of leveling and of placing concrete was done in the open air. From a point just below low water, the concrete pier was carried up with a facing of cut stone. The time occupied in sinking the caisson was nine months.

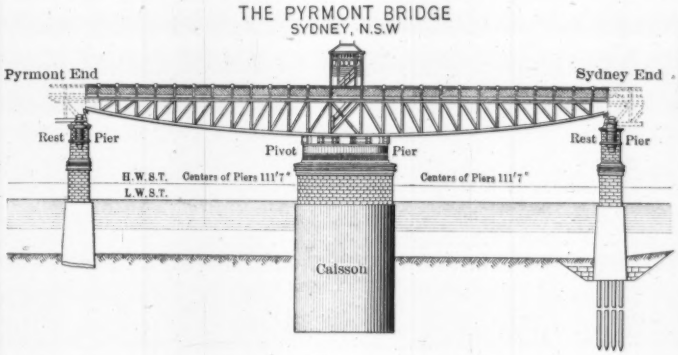


FIG. 4.

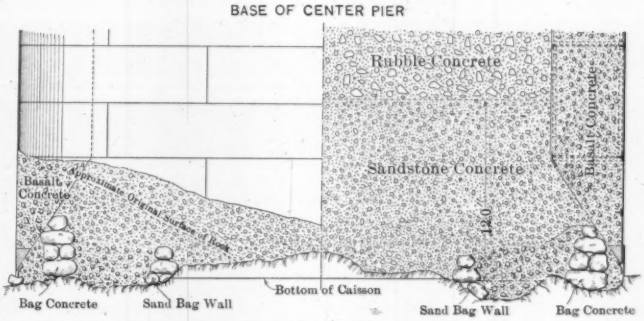


FIG. 5.

The thickness of the wrought-iron shell used in the caisson varied from $\frac{1}{2}$ to $\frac{5}{16}$ in., and the concentric rings were connected with angle-bar bracing.

This bridge was opened for traffic in June, 1902.

Method of Placing a Typical Pier for the Bristol Bridge.—The method adopted was to drive a timber coffer-dam of a single line of 12-in. material, between guides, and to caulk this with oakum, making

Messrs. Francis and Marshall.

a dam to hold back 28 ft. of water at high water and about 2 ft. at low water.

Excavation was made in the open without trouble to a point about 6 ft. below low water, when several blow-outs occurred at times of

RIVER AVON BRIDGE, BRISTOL, ENGLAND

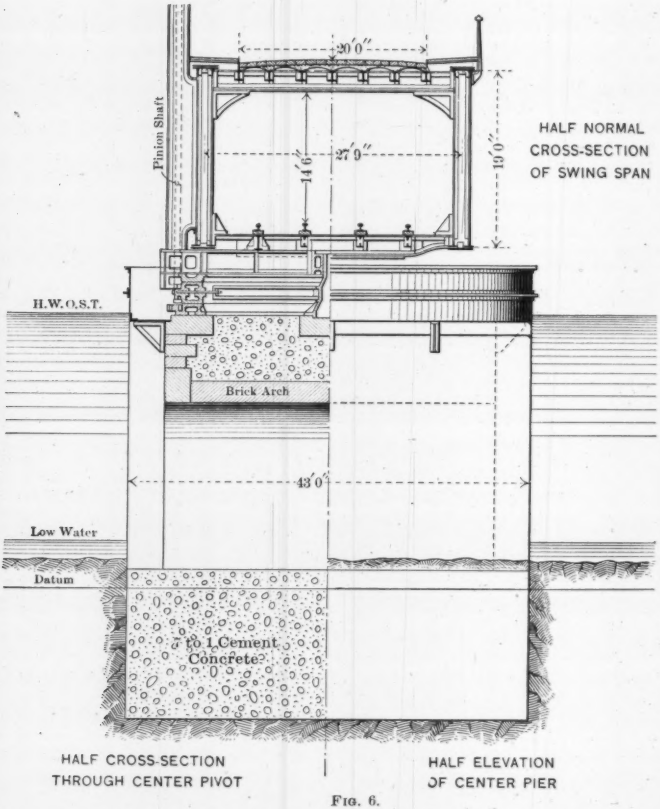


FIG. 6.

high tide, after which excavation was carried on only at low tide. Concrete foundations were placed in air, at low-tide periods, to low-water elevation, and, above that elevation, the concrete core was faced with cut stone and laid up in the open air at all stages of the tide.

A double line of timber sheathing for the coffer-dam was not practicable on account of the waterway required for navigation. Messrs. Francis and Marshall.

F. W. SKINNER, M. AM. SOC. C. E.—Most deep piers have been sunk through soft material by using open steel caissons or pneumatic caissons. Mr. Skinner.

The possibilities of the open-caisson method are illustrated by two cases: One was the sinking (on two different occasions) of the extremely deep pivot piers of the Omaha Bridge. These piers were made with double steel cylindrical shells, sunk more than 100 ft., to a satisfactory bottom, by dredging, undermining the cutting edge, loading, and jetting. After the excavation was completed the interior chamber was filled with concrete.

Another very interesting example is shown by the river piers of the Poughkeepsie Bridge, which, like those of the Interprovincial Bridge at Ottawa, and various other examples not so well known, were made with timber cribs sunk by loading the pockets and dredging the interior. Those of the Poughkeepsie Bridge were sunk more than 120 ft.

In such work, the principal objection—a very strong one and made frequently—is the difficulty of inspection and the uncertainty of the bearing and character of submerged work. Of course, divers can be sent down, but most engineers have a rather well-founded prejudice against implicit reliance upon a diver's report, for something has to be accepted on chance. However, those methods of pier construction are of great value. So, also, are the pneumatic-caisson methods; but both are costly, especially the latter; and, as the ratio of cost increases, the desirability of supplementing them by some other and less expensive method also increases. The speaker is thoroughly convinced that, within a very few years, the open caisson of rigid steel will be superseded in many instances by its equivalent, a sectional steel caisson, which, as Mr. Francis has suggested, should be made of interlocking piles.

The advantages, or some of them, are obvious; the greatest, probably, is that such caissons are sunk very readily. The rigid steel cylinder has to be sunk as a unit, and the frictional resistance to be overcome is enormous, amounting to thousands of tons, and it soon increases entirely beyond the possibilities of operation, as is often found in sinking tunnel shafts. A cylindrical shell can be carried 30 or 40, or even 50 ft., and then it generally becomes immovable owing to the frictional resistance or because of contact with large stones. All portions of it must move uniformly and simultaneously, and it is impossible to concentrate or increase the force at any one point; the sinking force must increase directly with both diameter and length of shell. In a sheet-pile caisson, each pile is sunk independently; the whole available force may be concentrated on it, and the force being successively applied to the piles is moderate and does not

Mr. Skinner. increase with the diameter of the caisson. Mr. Francis mentioned another important point, but did not enlarge upon it, namely, that a rigid steel cylinder can only be sunk to the highest point of rock, whereas, by the use of a large number of strong, narrow units, a sectional steel caisson can be operated independently, can be sunk regardless of inequalities, and made to conform to the rock surface, and each section can be carried on as far as necessary.

Hitherto, the objections to the steel cylinder or polygon have been two: first, that up to five or six years ago steel piling did not exist; and, second, that since its development, which has been phenomenal, and its adoption, which has been equally remarkable, there has not been, until very recently, a real water-tight joint. Joints can now be made actually water-tight; previously, it was hoped that they would be water-tight. In some instances leaky joints were finally made approximately water-tight, either by filling, caulking, grouting, or by the deposit of material in them; but those methods of tightening are slow, costly, and uncertain, and not to be relied upon. Now there is in the open market a spring-lock steel piling which is absolutely water-tight, and is capable of withstanding very heavy pressures.

Furthermore, steel piles, as generally known heretofore, have been largely adapted to extremely heavy work. They would stand a great deal of punishment, but were not elastic in their design.

It is now possible to secure steel piles which are entirely elastic in design, and may be made to conform to any conditions of loading or pressure, and to almost any conditions of driving. In fact, the joint is pliable and elastic, and "live," under any requirements which may be imposed by the designers, and any given degree of strength, elasticity, or rigidity may be secured. Therefore, the speaker believes that sectional steel coffer-dams will be successfully and generally used.

In the construction of previous work there has been much difficulty in driving any sort of piling, not only on account of the spring and the natural trouble in driving very long units, but on account of maintaining the alignment and interlocking. Those difficulties are in a fair way to be well solved by methods devised for installing sheet-pile units of great width and small thickness; and applications of temporary and removable reinforcement will solve many other difficulties incident to hard driving, so that the steel piling can be profitably used in many new cases.

There recently came to the speaker's notice, and was the subject of considerable study and detailed designing, a case where it was likely to become desirable to build a sectional steel-caisson cylinder of the interlocking type, under uncertain conditions where it was thought that, while it might be sunk successfully to a hard stratum, it might, on the other hand, be stopped sooner by serious obstacles such as logs or boulders. It was found to be entirely practicable to build

a simple, cheap caisson for these conditions, and a detailed design was made which enabled the sectional coffer-dam to be sunk to a previously unknown depth as a steel-pile proposition, but which also provided for the transposition of that form of construction to the pneumatic-caisson construction, should any obstruction be encountered which made the further driving of any of its component units too difficult. Mr. Skinner.

The details were very simple, and, when submitted to contractors of large experience in pneumatic-caisson work, met their unqualified approval, so that it was not entirely chimerical. Although the proposed work was not eventually executed, it was evident that without incurring any additional preliminary expenses, beyond what would have been required for an ordinary steel-pile proposition, the cylinder could have been started and sunk as deep as proved feasible and then transformed quickly to a pneumatic caisson at a very small additional expense, thereby saving the large expense of initial pneumatic-caisson construction which might not prove necessary and would at best impose a form of construction inimical to the most economical or rapid work. If air pressure were ultimately resorted to, it would be under more favorable conditions than if at first applied, and a large difference in the cost of the work would be saved.

So much for the steel pile; but that does not entirely cover the ground. It is well assumed, in the light of developments which will be made public in the near future, that various kinds of substructures with a wide range of materials, functions, and dimensions, can be built underground in some of the most difficult soils, by a new and very simple unit method, not at all experimental in its nature, which will greatly increase the rapidity, accuracy, and efficiency of installation of coffer-dams, retaining walls, core-walls, abutments, foundation footings, piers, all kinds of steel sheet-piles and sheeting, pipe and conduit laying, sewer building, and many other kinds of concrete and reinforced-concrete work. This method eliminates serious difficulties heretofore obtaining in the execution of such work; assures very great accuracy and certainty of inaccessible connections; and facilitates the reduction to the theoretical working limits and stress sections of members which heretofore have had to be given excessive dimensions in order to provide for construction requirements which were unnecessary for the final functions—for instance, great strength and weight in steel or other sheet-piles to resist the abuse of hard driving.

These two important new propositions: water-tight steel sheet-pile units of elastic design, suitable for easy and difficult caisson and coffer-dam work and cheap enough for ordinary trenching and general wet excavation, and substructure installation by the unit system, have been for several years under investigation and experiment, the designs have been thoroughly revised and approved, and, as soon as commercial arrangements are perfected, will be publicly demonstrated, exploited,

Mr. Skinner. and put under contract competition. The speaker believes that they will have an important influence on foundations and other substructure work, especially in soft, wet or plastic soils.

Mr. Wiley. H. L. WILEY, JUN. AM. SOC. C. E. (by letter).—A study of various bridge foundations constructed during the past twenty years discloses numerous cases in which greater economy and equally satisfactory results might have been obtained by methods other than the ones used.

Pneumatic caissons have been used in instances where, to base one's criticism upon the available records, the work could have been performed in less time and for less money by other means. In addition to the increased time required for pneumatic work, the costs of finished foundations would seem excessive. There is, however, a factor of assurance in pneumatic work, and a greater degree of certainty that the work will progress without serious delays.

Often the success or failure of the open-caisson method, from the standpoint of those who pay for the work, is more or less in the hands of the persons making the preliminary investigations in the field. Carelessness, inexperience, or direct neglect of duty on the part of the investigators, has meant added and unnecessary expense in open-caisson work, where an accurate knowledge of the material under the ground surface is so essential for economy.

The writer concurs with Mr. Skinner and Messrs. Francis and Marshall as to the value of interlocking steel piling for work of this class, but numerous conditions can exist which might render the steel piling more costly than a caisson or coffer-dam of another type. If the steel piling forms part of the permanent structure, the cost of the pier may be greater than if steel plate were used to form the shell of the caisson. The salvage value of steel piling after it has been once used in heavy work is greater in theory than in fact. Where the material penetrated contains logs or boulders, the piling gives trouble, and an obstruction that would often be forced aside by a heavy caisson, or which could be removed when encountered, may easily displace the steel piling and destroy the connection with the adjacent sections, resulting in a costly complication.

With a concrete shell the enclosed space may usually be cleared of water soon after sinking commences, but with steel piling the work of unwatering and excavating is directly dependent upon the success of the driving, and cannot be commenced until that part of the work is completed.

Mr. Skinner states that in open-caisson work the "sinking force (required) must increase directly with both diameter and length of shell." The skin friction on the lower section of the caisson increases directly as the depth sunk, but, unless the material is very unstable or practically in a liquid state, the friction at any given depth on successive sections of the caisson is not as great as that exerted on the

cutting edge and lower section of the caisson while at that point; or, in other words, the passage of the lower part of the caisson smoothes, lubricates, or in some other manner tends to decrease materially the friction on the following sections. Mr. Wiley.

A wall thickness of 5 or 6 ft. gives weight enough to overcome any friction that may develop ordinarily, unless the material penetrated be exceptionally difficult. Table 2 illustrates to some extent the wide variation in the amount of friction in such work.

TABLE 2.

No.	Type of caisson.	Method of sinking.	Materials penetrated.	Skin friction.	Depth below low water, in feet.	Area of base, in square feet.
1	Cast iron	Open excavation	Gravel, clay	240	60	125
2	Cast iron	Open excavation	Sand, clay	250	75	225
3	Cast iron	Open excavation	Sand	250	60	125
4	Wrought iron	Open excavation	Sand, clay	285	140	1 000
5	Cast iron	Open excavation	Sand, clay, gravel	300	100	125
6	Cast iron	Open excavation	Sand	325	60	125
7	Cast iron	Open excavation	Silt	350	60	125
8	Steel construction	Open excavation	Silt, sand, clay	375	55	190
9	Cast iron	Open excavation	Silt, mud, clay	390	75	100
10	Timber construction	Open excavation	Sand	450	30	1 300
11	Steel construction	Open excavation	Silt, clay	450	60	700
12	Steel construction	Open excavation	Silt, clay, sand	450	60	1 200
13	Steel construction	Open excavation	Mud, sand	450	65	1 300
14	Steel construction	Open excavation	Clay	450	75	1 500
15	Iron construction	Open excavation	Sand, gravel, clay	480	65	200
16	Cast iron	Open excavation	Clay	500	60	125
17	Steel construction	Open excavation	Clay	700	65	1 300
18	Masonry	Pneumatic	Sand, mud	205	40	75
19	Timber construction	Pneumatic	Clay	250	35	800
20	Steel construction	Pneumatic	Clay, sand	275	60	150
21	Timber construction	Pneumatic	Silt, sand, mud	310	75	2 550
22	Timber construction	Pneumatic	Sand, clay, gravel	350	100	1 200
23	Timber construction	Pneumatic	Sand, clay, boulders	400	48	1 925
24	Timber construction	Pneumatic	Clay, sand, gravel	400	95	4 500
25	Timber construction	Pneumatic	Sand, gravel, clay	425	55	1 300
26	Steel construction	Pneumatic	Sand, boulders	450	68	2 700
27	Timber	Pneumatic	Silt, clay, gravel	500	75	1 800
28	Iron cylinder	Pneumatic	Sand, shale	525	60	1 200
29	Timber construction	Pneumatic	Sand	540	75	1 700
30	Timber construction	Pneumatic	Sand, clay	600	75	1 400
31	Timber construction	Pneumatic	Sand, gravel, clay	650	80	2 000
32	Timber construction	Pneumatic	Sand	650	90	1 200
33	Timber construction	Pneumatic	Sand, boulders	660	101	2 100
34	Timber construction	Pneumatic	Silt, sand, clay	900	45	1 700

In many cases an "all concrete" caisson could be used to great advantage. The cutting edge of the caisson could be protected and strengthened with a sheathing of steel plate for 5 or 6 ft. A channel, riveted to the inside lower edge, would hold the first section in shape and offer a support for the concrete forms at the cutting edge.

This channel would be subject to the heaviest duty, and, with the plate, would prevent serious damage if boulders or timber should be encountered. With a caisson of this type, all concrete could be

Mr. Wiley. deposited in the dry, unless there might be a stratum of porous material containing water under heavy pressure above the bed upon which the caisson would finally rest, as was the case at Fort William.

The steel shell of an open caisson is often of no actual value except as a form for the concrete, and, in cases where it might easily be eliminated, it would seem to be an unnecessary expense.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1095

NOTES UPON DOCKS AND HARBORS.*

By Luther Wagoner, M. Am. Soc. C. E.

With Discussion by Messrs. W. B. Ruggles, E. P. Goodrich, Howard J. Cole, and Rudolph Hering.

During the year 1907 the writer visited the principal ports of Europe and the United States for the purpose of procuring data for the preparation of a report upon the future needs of San Francisco in the matter of port improvements.

For the foreign work he had exceptional facilities for observing completed works and receiving information concerning new or projected work. As a result, he obtained a large quantity of technical literature, maps, plans, and photographs, as well as notes, and, believing that some of the data obtained may be of general interest to the profession, he has prepared the following paper.

Comparison of European with American Harbors.

A striking difference in the ground plans of port works is at once apparent to the visiting engineer. The development by piers or jetties, like that of San Francisco or New York, has no parallel. Generally speaking, the European idea is one of enclosed basins, with or without locks, as tidal conditions may require. In the Mediterranean, where the tide ranges from 10 to 20 in., there is usually no protection

* Presented at the meeting of September 2d, 1908.

from the sea, so a mole or breakwater is built and behind it a safe harbor is created by dividing up the protected area into basins separated by solid filled piers, usually from 300 to 400 ft. wide. Upon these piers there is first a space of from 20 to 25 ft. for cranes and one railway track. Next are the sheds, from 75 to 130 ft. wide; then there is an open space between the sheds for two railway tracks, and a wagon road between them. At Naples it was necessary to build such a wall in 110 ft. of water; at Genoa, in depths of from 50 to 70 ft., and at Marseilles from 60 to 75 ft.

At cities like Antwerp, Rotterdam, Bremen, and Hamburg, on tidal rivers, the problem has been one of obtaining the desired area by dredging out basins and enclosing them with quay walls, leaving sufficient space for railway connections, sheds, warehouses, and roads, the whole being arranged so as to facilitate business. In this matter it is specially noteworthy that railway connections have been provided at all points, and, generally speaking, freight can be transferred directly from the ship to the car or *vice versa*, thus avoiding delay and extra handling.

Liverpool, which is essentially a receiving and forwarding port, has perhaps the best arrangement of railways and stations. In a length of 6 miles of water front there are ten or more great railway freight stations, all being just at the rear of the docks. In point of efficiency of belt-railway service, there is nothing at present in the United States that is comparable with that of any first-class European port. Within the City of Philadelphia there are more railway lines connecting manufacturing establishments with the various roads than in any other city of the same area, but, on the other hand, the railways own and control about 80% of the available water front. New York has no belt-railway, and it is doubtful if it will ever have one, as the price of land required for it is prohibitory. San Francisco is fortunate, in this respect, as the State owns the water front, along which there is a street 200 ft. wide, and upon which there is a State belt-railway. If the recent plans for the port improvements are carried out, the new street along the water front will have a width of 350 ft., upon which there will be ample room for belt-roads, warehouses, and railway freight stations, as well as street cars and other vehicular traffic.

In Europe the systematic planning of new work is especially note-

worthy. For example, in Antwerp, a broad, comprehensive scheme of port enlargement has been carefully prepared, and is of such magnitude that it will require many years for its execution. The Board of Control has acquired the lands, and planned the roads and rail connections long in advance of actual needs, thus permitting its orderly execution without regard to any vested interests. As the city grows up around the new port, it will not have to make expensive changes. Similarly, Rotterdam has planned a gigantic basin where it is intended to dredge 650 acres to a depth of 40 ft. and deposit the soil on the low lands below. It is estimated that the completion of this work may require from twenty to thirty years. All the larger ports in Europe are planning and executing systematic extension of their facilities to hold their present and secure a share of expected increased trade. Coincident with such work, much attention is given to making the city attractive, a place where one would like to live, and where a visitor would like to go again. They have, in general, a good administration, and are able to select and keep employed men of ability to administer the public utilities. As a rule, they look further ahead than Americans; in other words, they think more before taking action.

Statistical Chart.

Among the duties imposed upon the writer was the request to try and forecast the amount of the future commerce of the port of San Francisco, and plan improvements ample for such purpose, say fifty years hence. The method of investigation and the results are shown upon the diagram, Plate IX. After a preliminary study of the data, it was found that, owing to the rapid increase in the quantities platted, and the natural irregularities of the subject, the ordinary method of showing the time relation was not suitable for prediction purposes, and the logarithmic method was used. In the diagram, Plate IX, the year 1700 is zero, 1800 is 100, and 1900 is 200, and the logarithms of these numbers were used for the time scale. Four vertical scales of 1 to 10 were drawn, so as to cover all the data used without confusion of lines. In such a diagram an inclined line denotes an exponent; for example, the average line drawn through "Value of Merchandise Exports and Imports, United States," is the graphical representation of

$$\text{Average value} = 0.0000244\ (\text{Year} - 1700)^{6.06}.$$

For Hamburg's tonnage, the exponent is about 10, and for the population of the United States the exponent is about 4. The degree of accuracy of this method of forecasting can be readily seen by going back, say, to 1870 or 1880, and projecting ahead to the present time. The application of logarithmic platting to such purposes is believed by the writer to be new.

It is commonly held by experts that the production of pig iron and steel is a good financial barometer. The production of iron and steel (not shown on Plate IX), the horse-power used in United States manufactures, and the total bank deposits in the United States are three curves which can be almost exactly superimposed by moving them vertically into position; in other words, they have a common exponent or law of increase.

Some very interesting conclusions may be drawn from this diagram. For example, up to the year 1900, London and Liverpool tonnage were moving at a common rate of growth. London then needed port improvements, but expended its energy in discussion (and a very thorough one it was), while Liverpool deepened and extended its docks; the result can be plainly seen upon the diagram after 1900. The diagram also shows that the exponent of increase of population in the United States is about 4; exports and imports of the United States, about 6; world's commerce, about 6; United States bank deposits, about 10; the horse-power, and manufacture of pig iron, steel, etc., about 11 to 13; consequently, per capita, this means a rapid increase of business for the engineer, because the increase in such activities, referred to a time relation, is measured, per capita, by the difference in exponents.

The data relating to steamships are quite interesting. They were compiled from a valuable report,* by Elmer L. Corthell, M. Am. Soc. C. E. Attention is called to the very rapid and uniform increase in the average tonnage of vessels, about 841 tons in 1873, 1 955 tons in 1903, and now about 2 300 tons.

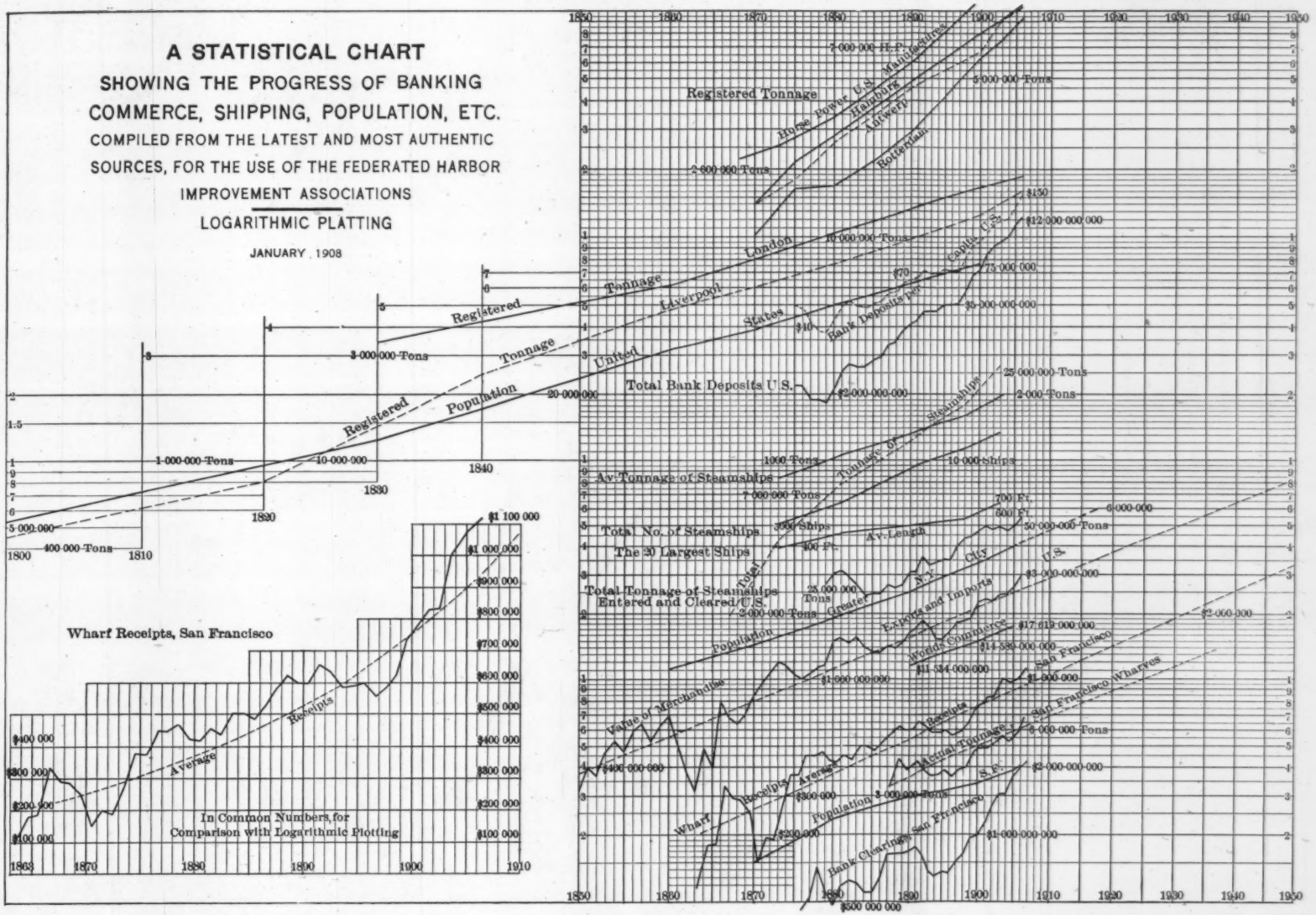
The draft (loaded) of a vessel can be expressed by an equation in this form:

$$\text{Draft} = K\ (\text{length} \times \text{breadth})^{\frac{4}{3}},$$

in which K ranges from 1 for small vessels to 0.88 for those of the largest type. There is no doubt that K would be uniformly taken

* To the Tenth Congress, Milan, 1905, Permanent International Association of Navigation Congresses.

PLATE IX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXII, No. 1095.
WAGONER ON
DOCKS AND HARBORS.



about 1, if the depth of water in ports permitted it. It is quite probable that vessels will go on increasing in general dimensions, because it is more economical to do transoceanic business in large vessels of great depth than in small ones. Naturally, there must be an almost general work of deepening ports and docks before there can be any great advance in draft. The average ship is a tramp, and does business at any place, and, for the present, not many ships of great draft can be operated, and those only between ports in which there is the requisite depth of water and dockage; but it may confidently be predicted that the natural economic law of draft will involve the universal deepening of at least all the world's greater ports.

Very notable is the relation between the exponent of growth of population of the United States—about 4—and that of the trade of the United States and of the world's commerce—about 6. This means per capita: An increase as the square of the time since the year 1700, or, for every dollar's worth of trade per capita now, about $1.50 of trade 45 years hence.

Still more marked is the relation, if population be compared with such activities as the production of steel and pig iron, horse-power used in manufactures, and bank deposits. All these activities have increasing exponents, the difference being from 6 to 9, which means that, per capita, in the United States these activities are increasing as the 6th to the 9th power of the time, measured from the year 1700, all of which points to an ever-increasing demand for competent technically trained men to direct such service.

Concrete Piles.

Concrete piling has been used in Ravenna, Venice, Boulogne, Rotterdam, Hamburg, Southampton, and a number of places. Speaking generally, the experience has been satisfactory, although in some cases serious difficulty has been encountered in driving such piling. Some trouble was observed in Hamburg, where concrete piles, from 30 to 36 ft. long, were being driven for the launching ways of a shipyard, many of the piles being badly broomed and broken. In this case, they were driven in a sand fill, without the use of a water-jet.

Southampton is the best place at which to observe such work, as experience there covers a longer time, and the piles are of greater dimensions than elsewhere. At the time of the writer's visit, 15 by 18-in.

piles, 60 ft. long, were being driven as sheet-piling at the front of a quay wall which had failed by sliding outward. These piles were driven about 30 in. in front of the wall by using a jet and a steel bonnet lined with a cushion of sawdust. The penetration was 28 ft., a heavy steam hammer being used for driving. Embedded in each pile near its center there was a $\frac{3}{4}$-in. iron jet pipe with an elbow about 2 ft. from the top. At the bottom this pipe was screwed into a cast-iron point; the nozzle opening was $\frac{3}{8}$ in. The pressure was 200 lb. and the quantity of water used was from 5.5 to 6 cu. ft. per min. A period of at least 60 days was allowed for seasoning. No trouble was experienced in driving, and no brooming or breakage was noticed.

At this place there is a coal wharf on reinforced concrete piles which also has diagonal braces of concrete and a concrete deck. This wharf has been subjected to an unusual amount of buffeting and hard service, and is quite elastic. Two piles which were broken off under water by a collison were repaired by divers. The broken parts were removed, then an iron tube was inserted and caulked in place, after which the tube was pumped out and filled with concrete.

Extensive improvements being under way for the London & South Western Railway (the owner of the docks), their engineer, Mr. Shields, had just completed a careful inspection of all concrete work. He reported that all work below water was in sound condition, but that a few remarkable cases of rusting and exfoliation had occurred above the water, for which no satisfactory explanation could be found. In this the writer saw a very strong resemblance to the failure of expanded metal in concrete floors, reported to the Structural Association of San Francisco in 1906. As a final result, it was decided that for any new work at Southampton, there should never be less than 2 in. of concrete covering the reinforcement, both above and below water.

At Paris the writer was informed by E. T. Quinette de Rochemont, M. Am. Soc. C. E.,* that although the length of experience with reinforced concrete piles was not greater than from 5 to 7 years, he was favorably impressed, and that the Corps of the *Ponts et Chaussées* would use them freely if the conditions required it.

Young's million-dollar pier at Atlantic City is an example, on a large scale, of the use of concrete piles. These piles have a riveted case of $\frac{3}{16}$-in. steel to which is secured a concrete point. They were hoisted

* *Inspecteur Général des Ponts et Chaussées.*

into position and filled with concrete to a depth about equal to the water; they were then lowered and put down by jetting about 15 ft. into the sand, care being taken to have the concrete filling at all times above the surface of the water. There are no reinforcing rods, and, when the outer galvanized cylinder fails, the structure must depend on the tensile strength of the concrete to resist the lifting action of the waves, which, owing to the exposed position of the pier, may be quite severe during a storm.

The Wear of Concrete.

Most of the quay walls observed in Europe are faced with rubble or ashlar. In Belgium, Holland, and Germany they have a rubble facing of hexagonal basalt blocks about 2 ft. deep, to prevent wear. In the Albert Dock, London, a concrete non-faced quay wall has been in use about 30 years, and, having been subjected to much buffeting from lighters as well as ships, it has worn away about 2 in.

Careful inspection was made as to a possible action at or near the water line due to freezing, or wave action, or both, but nothing noteworthy was seen. However, at Baltimore there is a noticeable exception, for, on certain bridge piers, and for a vertical range of 18 in., the concrete has disintegrated to a depth of several inches about at the ordinary water line. Aside from the affected part of the concrete, which was covered with a vegetable growth more dense than in the lower unaltered part, nothing unusual was observed. The concrete above and below the affected zone is good.

Various theories have been advanced to account for the decomposition. The most plausible one is that, with a small tidal range, there is a destructive action by the waves lapping the affected zone, and this, perhaps, is assisted by ice action. None of the theories suggested, when weighed and considered in reference to similar structures elsewhere, appears to the writer as tenable. Believing it worthy of investigation, the matter has been reported to the United States Geological Survey, with a request for an investigation and report.

Concrete Caissons.

In Europe extensive use is being made of hollow concrete caissons, both plain and reinforced, for breakwaters and quay walls. The structure is towed into position and sunk, after which the hollow cells

are filled. Some of those used for breakwaters weigh more than 5 000 metric tons.

At Rotterdam, caissons 131.2 ft. long, and having a width of 32 ft. at the base and 16 ft. at the top, and 43 ft. high, were being used. A middle division wall through the length, and nine cross-walls, divide the caisson into twenty cells. Four such caissons were built at the same time in an improvised dry dock. The first step was the preparation of a base, about 2 ft. thick and 32 by 131.2 ft., well reinforced, and in this were embedded the vertical rods for the walls. The external side walls, about 14 in. thick over the base, were carried up with a batter. When the caisson walls were up to about five-eighths of their final height, the gates were opened and the caissons were floated out to a place in the harbor where they were secured to mooring piles. There they were completed, meanwhile being afloat for one or two months.

As there are streaks of peat in the soil at Rotterdam, the bad parts are removed by a dredge, and then the dredged cut is filled with sand at least 6 ft. deeper than the base of the caisson. Then the caisson is towed into place, and, by means of a tongue and groove on the ends, the floating mass is brought into alignment, the free end being controlled by tackle. Next, by opening valves, the caissons are sunk on the prepared bed of sand, after which the water is pumped out of the front row of cells and these are filled with concrete; the rear row of cells is filled with sand to save expense.

In the older construction, the site was dredged, then a brush-mattress facing was placed, and this was allowed to stand for one or two years to secure thorough settlement of the mass on and to the rear of the mattresses. Afterward wood piles were driven through the mattress and, by using a special diving bell, were cut off and capped below low water; then they were decked with wood or reinforced concrete upon which was built the quay wall. The floating, reinforced concrete caisson method was stated to cost less per linear foot than for piles decked with concrete and more than for piles decked with wood. Practically, the cost may be said to be the same, with the decided advantage of a nearly monolithic wall.

Where rock is convenient, this method might be used with advantage: Having made the dredged cut, next place along the front line of the caisson one or more rows of piles, which might be driven to, or cut off, say, 2 ft. below the grade of the bottom of the caisson; and

then rock fill to grade; the object of the piles covered by rock would be to prevent any rotation of the concrete block around the outer toe due to a thrust from the shore side.*

Compressol.

In Paris the writer witnessed a demonstration of the Compressol method of preparing foundations. By a sort of pile-driver, a heavy conical weight is dropped repeatedly upon the soil, and, when the desired depth is obtained, small stones are dropped into the hole, and, by special forms of conical weights, are forced down and out into the soil, after which concrete is rammed into place by the same means. A completed pile will generally be 1 m. in diameter and have a bulb at the base.

One contractor in Belgium has eighteen of these machines at work. There are many places where such a system might be used; its special value would appear to be in a firm soil of loam requiring piling, and where the pile heads would be above the permanent water plane. Whether, in point of economy, it presents any advantages over some of the patented American systems is not known to the writer. It is asserted, by those advocating the Compressol system, that, owing to the thorough compression given to the ground, both laterally and vertically, combined with the mushroom-shaped base of the pile, it is capable of sustaining two or three times as much load as piles used in American systems. Certainly there must be considerable merit in it, otherwise it would not be used so extensively.

Wood Piles Driven at an Angle.

At Bremen, and notably at Bremerhaven, it is the practice to construct much of the new work in the dry. The area to be enclosed is stripped, by land dredges and cars, to 3 or 4 ft. below low water, and is kept dry by pumps. Along the proposed line of quay wall, two single-rail tracks are laid, about 33 ft. apart; these serve to carry a pile-driver which traverses a carriage supported by the two rails. The pile-driver is arranged to swivel in two directions; thus the driver can be placed with great precision and dispatch, and piles can be driven at any desired batter. It is the practice to select long piles, and first drive each tenth bent of piles. The ways are marked with a metric

* A good illustrated technical description of the work at Rotterdam may be found in *De Ingenieur*, July 20th, 1907, The Hague, Holland. This has not yet been translated into English.

scale, and an attendant records the position of the pile at each fifth or tenth blow. From these data piles of suitable length are selected for the intervening nine bents, and a similar record of driving is kept. Should one or more piles in a group settle too much during the last ten blows, a longer pile is driven in the bent or in the adjoining bents to give additional bearing power. The bents, when driven, batter about 1 on 5, like the letter A. At the cross of the A, two strong timbers are bolted to the framed piles, and longitudinal wales are bolted to the piles and side pieces, and a 6-in. wood floor completes the foundation. Upon this foundation a quay wall of rubble-faced concrete is built, and is bonded to the rear piles by tension rods, after which the area is opened and excavated to the full depth by dredges. A construction of this kind resists most effectively the thrust from the landward mass of earth, the outer piles being compressed and the rear piles in tension.

Mr. Claussen, Dock Engineer at Bremerhaven, says that he considers 15 tons per pile a safe load when used in tension. A number of long walls, such as the sides of a dry dock, quay walls, and locks in use for ten years, were remarkably straight, and offered strong evidence as to the value of this system of construction. This could not be used if limnoria or teredo were present, unless the piles in the outer row were covered by a concrete wall; but it might have application for mooring bits, etc., where the piling is protected, and perhaps would be advantageous where it is required to erect a temporary bulkhead and load the ground landward for a year or more, so as to consolidate it before commencing the permanent construction of a quay wall.

Cranes.

In nothing is the difference between the United States and Europe so marked as in the non-use here and the general use there of power cranes, usually hydraulic, but often electrically operated.

It is quite common for a merchant to visit Europe and, having noted the many excellent things to be seen, quite naturally think that among the improvements required in the United States are cranes.

In Europe several thousand cranes are installed; upon an average there is one crane to 283 ft. of quay wall, and their usage is quite variable.

At Marseilles, in 1903, thirty-four hydraulic cranes, having a capacity of 2 750 lb., worked 121 days per year for each crane, on a 9-hr. basis, and averaged 25.2 loads per hour. Ten cranes of double power, but working at one metric ton, worked 115 days; and working at 3 tons, 16 days each per year.

The whole number of loads was 1 116 980, which gave an income of 166 312 francs, or 2.92 cents per load. The average income of a crane was about $745 per year, which includes the power and the crane operator. This port has perhaps a more intensive use of cranes than those farther north, where generally only one crane out of four or five is observed to be working.

At London it is alleged that cranes do not pay interest upon their cost, but the ship owners insist that the dock owners have them and do not use them, except perhaps for a small part of a cargo.

It is possible that the crane idea is a survival from the days of sailing ships, when they were first introduced and were really required; next they were copied by other places, and by sheer inertia dock owners persist in having them. The people of the United States are quick to seize and appropriate a good idea, and the fact of the non-use of cranes, compels a strong belief that the appliances used—the ships' tackle and the stevedores' hoists—are ample. It has been asserted that a difference in the nature of the business done in the different countries is responsible for the general use of cranes abroad; but this does not appear to be a reasonable view of the matter.

The writer does not wish to give the impression that cranes are not useful; on the contrary, he believes that a partial adoption of the plan in the United States—to the extent, at least, of having wharf cranes which would serve to lift anything in excess of the capacity of a ship's tackle—might prove useful.

At Liverpool many cranes are supported upon the top of the warehouse front wall and a rail upon the peak of the roof. This is a very excellent disposition, because the crane is always out of the way.

Dock Strikes.

There is and has been much trouble at many ports in Europe from labor strikes, and, upon the whole, these are probably worse than any that have happened in America.

It is difficult for a stranger to form an accurate estimate of this

subject, because he hears various versions of the cause and nature of the trouble.

The writer questioned the officials of the ports visited, and, as a check, obtained the views of the marine underwriters and sometimes the Jesuit Fathers, who are usually in a position to estimate the troubles impartially. The general unrest appears to have below it a raising of the standards of living, for the cost of living and the wants of the laborer have increased faster than his wages. On the other side, the employers assert that, in view of the serious competition between ports, a small amount of extra cost will cause a diversion of business, therefore they oppose an increase of wages.

The nature of the work is irregular, there are periods of great activity followed by lessened opportunity for work. Genoa has been greatly troubled in the past by strikes, and the present port governing board, which is closely modelled on the lines of the Liverpool Dock Trust, has assumed that it has the power to settle such questions by creating a permanent force of laborers who perform any sort of service, from discharging cargo to road making, if required. The board takes on extra men for short periods to cover emergency cases. The laborers receive less pay than men engaged by private employers, and it is said that, on account of a strong union organization, they do less work. The outside criticism was, that the laborers practically dictated hours and terms to the dock board. The experiment is a valuable one, and its outcome will be a matter of interest.

During the writer's visit, a mild strike was in progress at Le Havre, and at Antwerp a severe one, which required the importation of some 2 000 English strike breakers, who, for their protection from assault, were housed on vessels in the harbor. In August the strike culminated in burning the timber yards and required calling out the troops in order to save the city from fire and quell the rioters.

To the writer, the wages seemed to be too low, but unless concerted action were taken by all the competing ports, it would be difficult to effect a raise. It does not appear that the form of government has any very decided influence upon strikes or violence arising therefrom. The striker is usually a voter, and some one in authority may need his vote. About the only safe deduction that can be made is that a small aggressive minority comes pretty near getting all it desires.

Average Data.

The following average data concerning foreign ports, compiled from a paper,* entitled "Results of Investigation Into Cost of Ports and Their Operation," by Mr. Elmer L. Corthell, and corrected by the writer in a few particulars, presents in a summarized form information of considerable interest:

The ports included are London, Liverpool and Birkenhead, Glasgow, Bristol, Hamburg, Rotterdam, Le Havre, Dunkirk, Bilbao, Antwerp, Bremen and Bremerhaven, the Tyne Ports, Marseilles, Amsterdam, Lisbon, Bombay, and Buenos Ayres.

Total cost of port improvements to 1906	$764 388 000
Registered tonnage, entered and cleared in one year (about 1905-1906)	185 652 000
Goods dealt with in one year, 1905-1906, in long tons of 2 240 lb., approximately	143 000 000
Gross revenue in one year (about 1905-1906)	58 206 000
Expenses " " " " " "	29 003 000
Net revenue " " " " " "	29 203 000
Gross revenue per registered ton " "	31.4 cents
Gross revenue per long ton " "	40.6 cents
Quayage length, in feet	1 192 000
Quayage length, in miles	227
Approximate length of rail, in miles	930
Length of rail divided by length of quayage	4.11
Ratio of area of sheds to quayage (44 467 770 sq. ft. of sheds to 1 067 120 ft. of quay)	41.1 to 1
Average weight of goods dealt with per year per linear foot of quay, in long tons	120
Percentage of gross income on capital cost	7.615%

One crane to each 283 ft. of quay wall.

General Reflections on Commerce.

The greatest factors to-day in the material and moral development of the world are transportation and commerce. By their agency, people and their products are moved from a region of a lesser to one of a greater use and demand. They are the greatest of all the civilizing

* *Proceedings* of Permanent International Navigation Congresses, Brussels, 1907.

agencies, because they promote an exchange of thought as well as of commodities.

The growth of modern commerce is closely interwoven with the development of the steam engine, railways, and electricity. It is a question of power and its applications, and its present enormous dimension is largely the work of the engineer. Its growth has been phenomenal, and is ever increasing; it is far more rapid in its rate of increase than that of population, which means increased wants upon the part of the people, and increased ability to buy and to enjoy. Its future is a question of great philosophical interest; but, until the people of the world are raised to the general level of intelligence of the more favored nations, it is reasonable to believe that its march will continue, and that day is so far distant that it does not immediately concern the present age. Until then, the signs point to an ever-increasing scope in the functions of the engineer.

DISCUSSION

Mr. Ruggles.

W. B. RUGGLES, M. AM. SOC. C. E. (by letter).—If, as the author says, there is a "striking difference" between the plans of the port works of the United States and those of European countries, there is quite as marked a difference of methods between the ports of the States and those of Latin-American countries.

Briefly, the prevailing custom south of the United States is to handle all freight to and from steamers with lighters. To some extent—but not entirely—this is due to a lack of good, deep-water harbors. There are few satisfactory harbors on the Pacific Coast of North and South America south of San Francisco. The peninsula of Lower California gives some protection to the few ports along the Gulf of California, but the deep-draft vessels going north from Panama, with sixteen regular ports, can only dock at Corinto in Nicaragua, Manzanilla in Mexico, lately completed, and Salina Cruz, at the western terminus of the lately constructed Tehuantepec Railway, in Lower Mexico. The latter port has been supplied by the Mexican Government with modern harbor facilities, and the railway is expected to compete sharply for transcontinental business. Steamers going south from Panama, with forty-five scheduled ports, find good piers only at two, Callao and Valparaiso.

On the Caribbean Sea, vessels coasting north find adequate docking facilities at Port Limon, and others are being provided at Puerto Barrios; but these are reported to be in comparatively shallow water. The northerly or Gulf port of the Tehuantepec Railway (Mexico) has the lately completed pier of Coatzacoalcos. Tampico has a Government steel pier and custom-house. Vera Cruz has a stone pier and a protected harbor 33 ft. deep. Atlantic steamers on their south-bound voyages can dock at Barranquilla and Cartagena.

There are a number of piers on the north coast of Venezuela, and, beyond Venezuela, on the east coast of South America, there are good harbors at long intervals.

The Island of Cuba is especially fortunate in its land-locked, deep-water harbors, and yet the bulk of the cargoes to and from foreign ports is handled by lighters, some coastwise sailing vessels being of such light draft as to reach the small landing piers usually found in shallow water. Havana Harbor is ideal; that bay, the Harbor of Cienfuegos—6 miles long and of good depth—and the Harbor of Santiago, with another 6-mile bay, are all as closely land-locked as they could be and give good entrances. Santiago has a pier for the Juragua Iron Company and a commercial pier, but not for vessels of deep draft. Guantanamo, 50 miles from Santiago, is a good harbor under improvement; but, as it has been taken over by the United States as a coaling station, it is hardly to be considered as a Cuban port. Car-

Mr. Ruggles. denas Bay is moderately well protected, but, except as dredged, is shallow at its entrance. Matanzas Bay, extending 6 to 8 miles inland, is open, but deep—more than 1 000 ft. deep within a mile or so of the old Customs wharf. Lighters are used in all these harbors. Nipe Bay, on the north coast, is now a terminal point for a railroad, and no doubt will be improved. Bahia Honda is a magnificent harbor, one of those which it was expected would be taken as a coaling station by the United States, but it has no port town of importance. Barracoa is good, and there are other fair harbors.

Except that in the course of nearly 400 years of existence the City of Havana has so encroached upon the bay as to make any kind of a belt railway very expensive, the harbor offers one of the best opportunities to provide the most modern facilities for the handling of the heavy passenger and freight business of what was once the fourth port of North America. In the ten years dating from the early American occupation of Cuba, plans for such improvements have been perfected, and in some measure approved by the Cuban Government, although, in the late adjustment of affairs, the present Provisional Government has apparently not found it advisable to give these projects precedence over the older and approved contracts for the sanitation of the city. Possibly the results of efforts to provide adequate harbor facilities for Matanzas may, in some measure, have led to this conclusion. Early in the former American occupation of Cuba, the Intervening Government was formally asked, by the city authorities at that port, to provide suitable harbor accommodations for the Bay of Matanzas, and after a year or so of preparation, in which the local, civil, and commercial interests were frequently consulted, and with no openly declared opposition from any interest, plans and specifications were submitted for a deep-water, creosoted-pile pier in the least exposed part of the bay, having permanently constructed connections with the two railways entering the city. One of the very last acts of the outgoing Intervening Government, after a full review of the situation with, and a hearty consent by, the new Cuban authorities, was the approval of the contract with a reliable New York firm for the construction of the pier, railway, steel bridges and other accessories, at a cost of approximately $300 000; with some subsequent modifications of plans and specifications, the works were built in 1902-03, but, in the five years since their completion, they have been used very little, if at all. The attitude of the local owners of the fleets of lighters and of the warehouses, of which Matanzas has an exceptionally substantial and extensive system on, or near, the San Juan River, has been distinctly hostile to the new arrangement, and, so far, they appear to have controlled the situation. It was hoped the new provisions would ultimately lead to more direct shipments from the interior of the island to the vessel. Even if the warehouse and lighter interests are themselves shippers, as it happens they are, it is

but natural that they should hesitate to support such a system, for their profits lie principally in handling the sugar, etc., at the port. Mr. Ruggles.

In Jamaica, a possession of the very commercial English people, there is an excellent closed harbor and deep-water pier at Kingston, and like facilities at Port Antonio on the north coast. The Port of Spain, in Trinidad, another English harbor, though not the deepest, provides at least for Royal Mail steamers.

The Danish port at St. Thomas has a floating dock. In San Domingo, a pier at Macoris, built under political grant, is reputed to have paid its considerable cost by port duties. The ports of Haiti are noted as "slow and inefficient." In Puerto Rico, San Juan is a dredged harbor, and, with other ports of the island, is being improved since it became an insular possession of the United States.

Before the construction of the Panama Railroad in 1850-55, Puerto Bello, 18 miles below Colon, was the desirable harbor on the Caribbean Sea, well protected and deep; it is still used as a shelter harbor at times of violent and long-continued gales.

The Harbors of Colon and La Boca, near Panama, were not naturally very good, both being originally shallow and, except for the islands in the Pacific, open, but the dredging for the Panama Canal makes their development into good ports reasonably practicable. All vessels can receive and discharge freight at the new wharf, No. 11, at Cristobal—that part of the harbor town within the Canal Zone. The Royal Mail and Hamburg-American lines still have their own piers at Colon, where, to date, they have proved adequate. On the Pacific side, the old French pier at La Boca, with its extensions, lying along the Canal line, provide berthing space for four or more large, deep-draft vessels at a time. These extensions were made about two years ago when it was presumed that the Canal entrance would be moved eastward to the point of Sosa Hill, and the new structures are, consequently, not of as substantial construction as the original French Canal company's pier, which is 960 ft. long, built 22 years ago with steel trusses and frames on steel cylinders, 5 m. in diameter, sunk to rock and filled with concrete. As the new train loads of the Panama Railroad are much greater than at the date of the construction of the pier, the two loading tracks have been removed from the trusses to a roofed pile trestle on the easterly side of the old shed, giving a correspondingly greater storage capacity; otherwise the structure is probably good for another generation. The new channel is being dredged to 45 ft. below mean sea level, and when the breakwater, now in course of construction toward Naos Island, is completed, the entrance to the piers will be well protected. The French company provided loading devices on the old pier and a very large crane of 15 tons capacity at the outer end for heavy machinery. On the late extension there are eight new electric cranes of nominally 8 000 lb. capacity—the writer

Mr. Ruggles. has seen 10 000 lb. handled on a trial. At Cristobal there are no cranes on Wharf 11, but at Pier 14 there is a large Brownhoist cantilever crane for coal, iron, etc.

Provisions are now being made for the construction of permanent piers between No. 11 and No. 14 along the Canal, the channel of which is kept dredged to required depth. Breakwaters are likewise proposed for this bay, and there is now a small dry dock above Pier 14.

Attention has lately been called to the fact that, except at the port of San Francisco and at Bremerton, Wash., there is no dry dock on the Pacific Coast.* This would seem to imply that the timber dry dock at Puget Sound, built in 1896, is not now available. Of the three at San Francisco, the largest is that of the San Francisco Dry Dock Company, 750 by 122 ft. The statement also fails to mention the dry dock at Salina Cruz, which is 600 by 100 ft., with a depth of 31 ft. In view of this fact and that commercial corporations and companies, such as the above and the Mersey Dock and Harbour Board at Liverpool, do not consider their port work complete without a dry dock, almost always a graving dock (one English firm, The Smith's Dock Company, on the Tyne, has six graving docks supplemented with two floating docks), it would appear desirable to have other harbors supplied with these provisions for cleaning and repairing. There is, it is true, a growing use of floating dry docks, but where there are, for instance, such good foundations within easy reach, with ample space and wide range of tide, as can be found between Corozal and the Canal, two or three miles inland from the La Boca piers, the cost of a permanent graving dock of large dimensions—double if necessary—would probably be no greater than for a corresponding provision for floating docks, if the additional repeated dredging for an operating basin, estimated as at least 50 ft. deep, for a dock of 30-ft. draft, shore anchorage works, etc., be added. At the site suggested it happens there could easily be coaling stations and railroad yards.

In late years the English Government has made great extensions in the harbors at which vessels are loaded with coal, notably that of Blyth, where improvements to cost approximately $900 000 are under way, and England, Holland, Denmark, and, to some extent, France, make special provisions for their fishing vessels. At the Boston, Mass., fish wharves this year nearly 1 000 000 lb. of fish were marketed in one day. As for the coaling staithes, or stations, the Pacific Coast may come in time to provide oil stations instead, but it cannot yet be said that there should no longer be any provision made for coaling steamers, for fuel, and for cargo.

Mr. Goodrich. E. P. GOODRICH, M. AM. SOC. C. E. (by letter).—Some investigations made by the writer in connection with the Meadow Reclamation

*Cassier's Magazine, March, 1908.

and Dock Commission led to the independent discovery, several months before the publication of Mr. Wagoner's paper, of several points brought out therein. Mr. Goodrich.

The rate of increase of population of many American cities, and approximately that of the United States as a whole, was found to be in a logarithmic ratio. A similar law holds for the foreign tonnage of many ports, thus providing a fixed relation between tonnage and population, and, in many instances, the growth of manufactures follows the same law. Because of these facts the per capita values of such commercial and industrial items are of great value in predicting probable future requirements of ports and communities.

Accurate plotting of statistics on logarithmic paper of large scale discloses many interesting facts, among which the following may be cited: At each war of any magnitude, the rate of increase of the population of the United States as a whole, and of a majority of its cities, received a check, and a changed rate was established. Commerce and industry are somewhat similarly affected, but to a much greater extent, by each financial panic which is almost literally a war in those lines.

Prediction of future port requirements is almost as complex as predictions concerning their tidal changes, but without as complete data. Railroad extensions and their rates to a certain port and to competing ports, the prompt adoption of improvements in handling facilities at those ports, the effects of natural limitations and advantages, the possibilities of change in the extent of neighboring industries, like fishing, lumber, grain, etc., in localities where these predominate, are some of the factors entering the problem when studying the necessities of such projects as those of Newark or Jamaica Bay, in the vicinity of New York City, or of increases in facilities in Baltimore, New Orleans, or San Francisco.

HOWARD J. COLE, M. AM. SOC. C. E. (by letter).—The author calls attention to the extensive use of concrete piles in Europe in connection with various harbor improvements, and incidentally mentions the patented systems of concrete piles in America. Mr. Cole.

Previous to 1902 the use of concrete piles in the United States was very limited, but about that time some methods of construction were patented and placed on the market, and since then their use has been constantly increasing; now there are structures in most parts of the country that rest on a foundation of this type, some of the installations containing 6 000 piles.

Concrete piles can be divided into two classes, depending on the general method used in their construction, viz., those "made in place" and those "moulded" before their installation.

In the "made-in-place" class, there are two systems in general use, both of which are patented, the "Simplex" and the "Raymond."

Mr. Cole. The "Simplex" concrete pile is formed by driving a hollow steel shell or pipe of 16 in. external diameter, into the ground to refusal by a heavily constructed pile-driver, the lower end of the pipe being closed with a patent shoe to prevent the entrance of earth. When the proper depth is reached, a charge of concrete is dropped into the steel pipe or driving form which is then raised about 1 ft. by a strong tackle attached to the driver; an iron rammer is then dropped inside the driving form and by its impact opens the shoe and forces the concrete out into the cavity formed by the withdrawal of the driving form. This process is repeated until the concrete has reached the required elevation, when the form is entirely removed, leaving the space it formerly occupied filled with concrete, thus making a concrete pile.

The "Raymond" concrete pile is formed by driving to refusal a tapering collapsible mandrel or form, covered with overlapping sections of sheet iron; then collapsing the mandrel and removing it, leaving the hole formed by the mandrel completely encased in sheet iron that serves as a mould for the concrete, which is placed within the casing as soon as the mandrel has been removed. These piles taper from a diameter of 20 in. at the top to about 8 in. at the point.

There is another pile that comes in the "made-in-place" class, though it is not strictly a concrete pile, and that is the "Clark," which is a steel-concrete pile, and is formed by forcing a steel pipe, about ½ in. in thickness and of 12 in. external diameter, to the underlying bearing stratum, partly by impact and partly by jetting, and then removing the earthy material from the inside of the pipe and replacing it with concrete, the steel shell being left in position and forming a part of the pile.

All these piles are reinforced, when necessary, by the insertion of steel rods.

The second-class or "moulded" piles are cast or moulded near the site, and then allowed to set or season before being jetted or driven into their final position. All piles of this class are reinforced to enable them to withstand the rough handling to which they are subjected.

There are many different types of moulded piles, the best known being the "Hennebique," the "Corrugated," and the "Chenoweth," each of which differs from the other in method of construction and cross-section, but all are driven in the same manner, either by jetting or by a hammer; in the latter case, it is necessary to provide a cushion between the hammer and the pile to avoid injury to the pile.

The "Hennebique" is square in cross-section of the same area throughout and heavily reinforced with steel rods placed near the corners of the pile, the reinforcement being tied together at regular intervals; a jet pipe is built in the center of the pile.

The "Corrugated" is a tapered pile, octagonal in cross-section, and has a deep semi-circular corrugation in the center of each side, which

increases its superficial area. It is reinforced with wire cloth and also contains a jet pipe, in fact practically all moulded piles are provided with jet pipes, though some solidly moulded piles have been successfully jetted into position by the method used with timber piles. Mr. Cole

The "Chenoweth" pile is circular in cross-section and maintains the same area throughout its entire length. It is made in a manner wholly different from any other pile, and is rolled, not moulded or cast like the others. It is formed by rolling wire cloth, plastered with mortar, around a jet pipe that serves as a core in the rolling process and later is used for jetting, the additional reinforcing being placed in proper position on the wire cloth before rolling; layers enough are added to make the pile of the required diameter, and it is then placed in the seasoning yard to harden.

"Made-in-place" piles have been built to a depth of 48 ft., while moulded piles have been used successfully up to 60 ft. in length.

Under ordinary conditions concrete piles are more expensive than timber piles, but, owing to their greater carrying capacity, they can be frequently installed at a considerable saving on the cost of timber piles, especially under favorable subsurface conditions.

RUDOLPH HERING, M. AM. SOC. C. E.—The speaker recently visited three of the harbors described by the author, viz., Liverpool, Hamburg, and Rotterdam, in all of which remarkable developments have taken place within the last two decades. Mr. Hering.

One of the differences between European and American harbors mentioned by the author, which the speaker thinks is the chief reason for the present excellence of foreign harbors, is that, in Europe, there are permanent boards or special commissions to lay out and design all the works pertaining to the entire harbor, and to carry out the different parts of the work, as they are needed, in order to make them conform to the intended plan. This plan embodies not only the docks, but also the railroads leading to them and the warehouses where goods are stored temporarily, and all the machinery for loading and unloading vessels.

Another difference between European and American practice is the fact that, in Europe, artificial basins are provided to a much greater extent than in the United States, because their rivers are smaller and their commerce is growing rapidly. Nowhere can there be seen slips placed at right angles to the river as in New York City. Neither in the Elbe nor in the Maas could big liners turn conveniently and enter such a slip without interfering seriously with the river traffic. Instead, the vessels generally enter at a convenient but small angle with the river, necessitating only a slight turn. In Hamburg and Rotterdam enormous excavations have been and are to be made for such basins, necessitated by the increasing traffic.

Mr. Hering. In nearly all cases the railroads come close to the dock lines. It is possible, particularly in Hamburg, which is perhaps the best arranged harbor in the world, to unload from the ships directly to the railroad cars or to the warehouses. This work is done by electric cranes, and requires very little labor.

Referring to the concrete work in the Liverpool docks, the speaker, during his first visit to Liverpool, in 1880, saw the iron or steel reinforcement of concrete for the first time. Some alteration in a dock had required the breaking through of one of the walls in which were several ¾-in. rods. They had been in the work for some years, and were absolutely without rust, which convinced the speaker of the practicability of thus fully protecting iron against corrosion. In Berlin, in 1880, he also saw the concrete work which formed the lower half of a sewer then under construction and still exposed to the sun. The interior was actually dusty, while the ground-water stood above the bottom of the sewer on the outside, proving that, with good materials and workmanship, it was entirely practicable to make water-tight concrete, a fact which was not then generally admitted in America.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1096

CATENARY TROLLEY CONSTRUCTION.*

By Oliver S. Lyford, Jr., M. Am. Soc. C. E.

With Discussion by Messrs. Joseph Mayer, Charles Rufus Harte, W. K. Archbold, Theodore Varney, George N. Cole, W. S. Murray, R. D. Coombs, and Oliver S. Lyford, Jr.

The catenary trolley work of the Denver and Interurban Railroad, in details of design and in methods of construction, exemplifies the special features involved in the problem of providing an overhead system for electric operation on roads using steam for motive power previous to and during electrification. Such roads generally have rigid regulations, and the operation of steam trains during the construction period imposes material limitations upon the work. The object of this paper is to outline some of the governing conditions relating to catenary construction for such roads, and the means adopted to meet these conditions in this most recent instance.

The Denver and Interurban Railroad is a part of the Colorado and Southern Railway System. This is the seventh large railroad system to inaugurate electrical operation on its lines, the other roads being the following:

Baltimore and Ohio Railroad: 750-volt third-rail in Baltimore Tunnel;

* Presented at the meeting of October 7th, 1908.

New York, New Haven and Hartford Railroad: 600-volt trolley on certain branches, and 11 000-volt single-phase catenary trolley on the New York Division and other branches;

Long Island Railroad: 600-volt third-rail on suburban lines, and 2 200-volt single-phase catenary construction on interurban line;

Pennsylvania Railroad: 600-volt third-rail on West Jersey and Seashore Division;

New York Central Railroad: 600-volt third-rail on main line, and 600-volt overhead trolley on West Shore Division and on branches;

Erie Railroad: 11 000-volt single-phase catenary trolley on Rochester Division, and 600-volt direct-current trolley on other branches.

Other large steam roads, now installing electrical equipment, are as follows:

Grand Trunk Railroad: 3 300-volt single-phase catenary trolley in Sarnia Tunnel and approaches;

Michigan Central Railroad: 650-volt third-rail in new Detroit Tunnel;

Great Northern Railroad: 6 000-volt three-phase trolley in Cascade Tunnel;

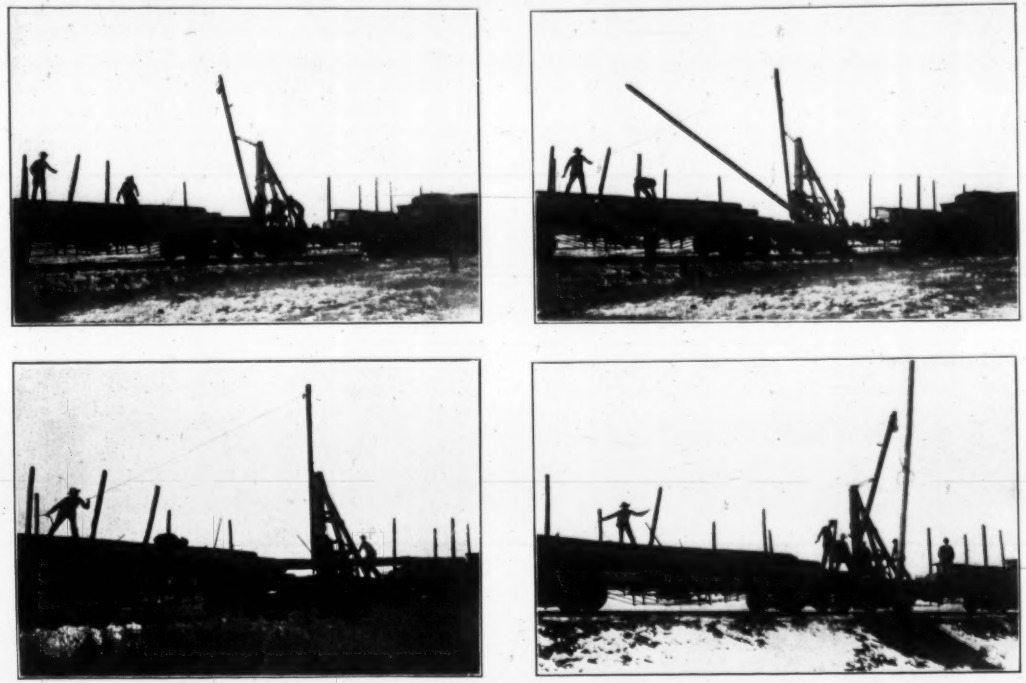
Southern Pacific Railroad: 1 200-volt direct-current trolley on Alameda Mole suburban lines at Oakland, Cal.;

Pennsylvania Railroad: New York Terminal and Tunnels—electrical system not determined.

The foregoing lists do not include any interurban trolley lines which were originally constructed as electric roads, or the few short steam lines which have been changed over to electric roads.

The Denver and Interurban Railroad is the fifth to adopt the single-phase system, and the third to use 11 000 volts on the trolley.

In the foregoing lists there are five roads using the direct-current third-rail system, two using the 600-volt direct-current trolley system, five using the single-phase system, one using the 1 200-volt direct-current trolley system and one using the three-phase alternating-current system. The last two systems have not met with general favor in America,



DERRICK CAR FOR SETTING TROLLEY POLES ON THE DENVER AND INTERURBAN RAILROAD.

and the single-phase system has been selected by most of the railroad companies whose decision to electrify has been made since the commercial success of this system has been demonstrated. The principal merit in the single-phase system lies in the ability to operate at high voltage with a single overhead conductor, and, therefore, to transmit power long distances with a minimum number of sub-stations and a minimum quantity of copper. These arguments apply particularly to trunk-line operations, and this system, therefore, appeals especially to the managers and engineers of large railroads. On the Denver and Interurban Railroad, the extent of curvature, the number of cuts and fills, parallel tracks, sidings, and other local features have introduced into this undertaking many of the principal construction problems which are likely to develop in a single-track road with moderately heavy traffic. Of the total length of track of this line, 43% is on curves.

The lines electrified are shown on the map, Fig. 1, and consist of a main line from the city limits of Denver to Louisville Junction, and two branches thence to Boulder. There is also a spur from the Marshall Branch to Eldorado Springs. The portion outside the terminal cities is equipped with the single-phase system. Within the limits of each terminal, operation is by the 600-volt direct-current trolley system. The cars, therefore, are equipped with electrical apparatus suitable for operation by either system. There are 44 miles of single-phase construction. In Boulder, the railroad company has provided 1½ miles of 600-volt direct-current construction. In Denver, the cars are operated on the city streets, over the lines of the Denver Tramways Company.

The principal features involved in the design and construction of such overhead work are outlined in the following notes:

Sufficiency.—The first cost of electrification work for railroads is high, but the cost of electrical operation is low, as compared with steam-locomotive operation, provided the equipment is properly designed, erected, and maintained. High-voltage catenary work cannot receive the close daily inspection of the track-walker, and, because this is so, there is the greatest necessity for thoroughness and permanence in the construction. Intelligence and experience, therefore, are at a premium in this field of engineering and operation.

Rapid Construction Work.—The details of design and methods of

construction must be worked out with special reference to rapid erecting operations. Time spent in the drafting-room in developing details which go together quickly means much time and expense saved in the field, where each construction operation is repeated hundreds of times. Much ingenuity can also be exercised in planning the field work. The accompanying photographs illustrate the quick methods of construction used in the Denver and Interurban work.

Work Train.—Much depends upon the proper equipment of the work train. For pole-setting, a derrick car is provided (Plate X), and, for overhead work, box cars are equipped with platforms at the proper height for convenient operation (Fig. 1, Plate XI). Where overhead obstructions exist, these platforms must be collapsible. The interiors of the box cars are arranged with storage bins, work-benches, tools, etc. Where construction is interfered with by the operation of schedule trains, the preparation work proceeds while the work train is on the siding, and everything is arranged for progress with the utmost despatch as soon as the main line is available.

Poles.—Poles are set at a distance of 8 ft. 6 in. from the center of the track to the inner side of the pole. This is sufficiently close to the track so that pole setting direct from the cars can be done to great advantage. The figures on Plate X illustrate such work. A record day's work with such an equipment, without interruption, is 117 poles set, including digging holes and tamping. This was done with 26 men. In one instance, 13 poles were placed in their holes in 15 min.

Bracket-Setting.—The effectiveness of the work train for bracket setting depends somewhat on the extent to which the line may be kept free from regular trains. Where interference is infrequent, the work train can be used to advantage in the manner indicated in Figs. 2 and 3, Plate XI. The locomotive places the cars opposite the poles, and bracket erection proceeds at four or five poles simultaneously. As soon as the brackets are in place, the locomotive couples up the cars and moves on. The brackets, of the type shown in Fig. 3, Plate XI, can be erected complete and adjusted to the right height at the rate of 150 per day, with 18 men and a work train of 5 cars. Fig. 3, Plate XI, shows the support placed on the top of the car for setting the bracket at the proper height, allowance being made in this setting for the deflection which will occur with the load of the catenary structure.

Placing Wires.—For placing wires the derrick car is arranged to

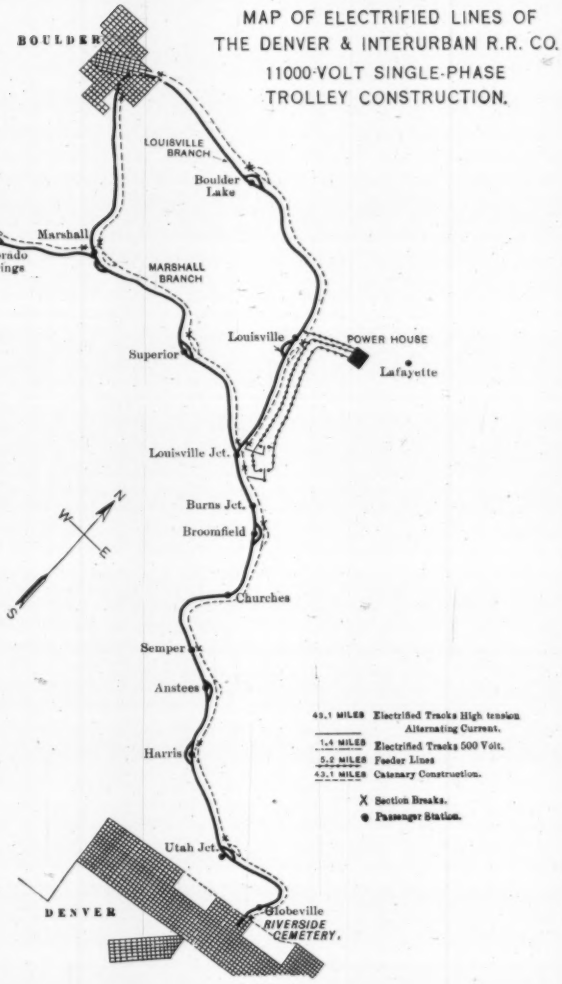

MAP OF ELECTRIFIED LINES OF
THE DENVER & INTERURBAN R.R. CO.
11000-VOLT SINGLE-PHASE
TROLLEY CONSTRUCTION.
BOULDER
LOUISVILLE BRANCH
Boulder Lake
Marshall
Eldorado Springs
MARSHALL BRANCH
Louisville
POWER HOUSE
Superior
Lafayette
Louisville Jct.
Burns Jct.
Broomfield
Churches
Semper
Anstees
Harris
Utah Jct.
DENVER
Globeville
RIVERSIDE CEMETERY
N
W
E
S
43.1 MILES Electrified Tracks High tension Alternating Current.
1.4 MILES Electrified Tracks 500 Volt.
5.2 MILES Feeder Lines
43.1 MILES Catenary Construction.
X Section Breaks.
Passenger Station.

FIG. 1.

carry the reels and pay the wire out over elevated rollers (Fig. 4, Plate XI). The best day's run on messenger wire was 7 miles strung and tied in. This took 17 workmen and two train crews. The best day's run on stringing and splicing trolley wire was also 7 miles, with 12 workmen and one train crew. The best day's record of clipping up messenger and trolley wire was 3½ miles with 13 workmen and one train crew. A working day consisted of 9 hours, with transportation from headquarters each day on the company's time, leaving about 7 working hours. The ground-wires and feeder-wires are placed before the brackets are erected, and the wire is paid out over the end of the boom of the derrick.

Adjusting the Sag.—The intention, in the design of catenary construction of this type, is that the trolley wire shall remain as nearly flat as possible, and the tension in the messenger wire and trolley wire must be determined with considerable definiteness between the minimum, which will prevent excessive deflection, and the maximum, which must be within safe limits for the material.

In the Denver and Interurban work the sag table used was that given in Fig. 2. To verify this table a special dynamometer was provided, consisting of a calibrated car-spring. The setting of the tension in the messenger and trolley wires by using this dynamometer on the top of the work train is illustrated in Fig. 1, Plate XII. The use of this dynamometer disclosed a point of interest in connection with the erection of long lengths of wire and cable. For an average sag of the messenger cable, which, according to the sag table, should result in a tension of 2 300 lb., the dynamometer showed an initial tension of 6 000 lb. This initial strain decreased to 4 000 lb. before quitting, and, after expansion and contraction over night, came down to the figure in the sag table. This excessive initial strain occurred on a portion of the line which is full of curves, and was due to the lack of equalization between the different spans of a 1-mile section. On tangents, the initial strain was between 3 500 and 4 000 lb. This is a point to be borne in mind in calculating the proper elastic limit for such wires and cables.

Pole Collars.—Experience with semaphores and other heavy structures on wooden poles has shown that such poles deteriorate most rapidly at the ground line and at points where bolts pass through the pole. With this experience in mind, the Denver and Interurban

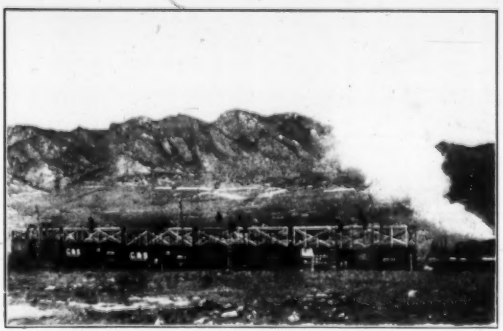


FIG. 1.—WORK TRAIN FOR ERECTING BRACKETS AND CATENARY.

FIG. 3.—ERECTING BRACKETS FROM WORK TRAIN.

FIG. 2.—WORK TRAIN DEPLOYED FOR ERECTING BRACKETS.

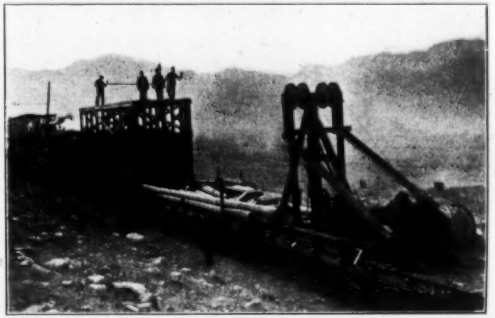


FIG. 4.—APPARATUS FOR STRINGING WIRES.

brackets have been attached to the poles with pole collars (Fig. 3, Plate XI), and no bolts pass through the poles.

Treatment of Pole Butts.—To increase the life at the ground line, the poles have been treated with carbolineum.

Ground-Wire.—In the Denver and Interurban work, a ground-wire, consisting of $\frac{7}{16}$-in. stranded galvanized-steel cable, has been strung over the pole tops for the entire length of the line. This wire has a number of functions:

It affords means for grounding the brackets and cross-spans so that working upon these parts is safe;

The ground connection of the running rails can be made at every fifth pole instead of at every pole, as would be necessary without this cable;

It affords a third circuit in parallel with the two running rails for the return current;

Being at ground potential and at an elevation above the trolley wire, it affords effective lightning protection;

It is a cheaper construction than the grounding of each bracket to the running rail and the addition of lightning arresters.

Track Connection of Ground-Wire.—Cross-bonding of the two running rails is necessary at frequent intervals. By placing these cross-bonds opposite every fifth pole it is possible to use the cross-bond as a means of connecting the ground-wire to the track, as shown in Fig. 6. A track connection of this kind is subject to abuse by the section men, and also from the vibration due to trains. A rather heavy ground-rod is necessary for protection from the section hand, and flexible connection to the rail is necessary because of the action of the trains. The combination of these requirements is best provided for in the manner illustrated. The conductor in this case is a $\frac{5}{16}$ by $1\frac{3}{4}$-in. iron strap. The flexible connection to the rail is obtained by attaching this strap to the center of the cross-bond. This gives a connection to each rail. The cross-bond is subject to the abuses of track repairers, but to a minimum extent. The figure illustrates the track connection for cross-span construction, but the same arrangement is used for bracket poles.

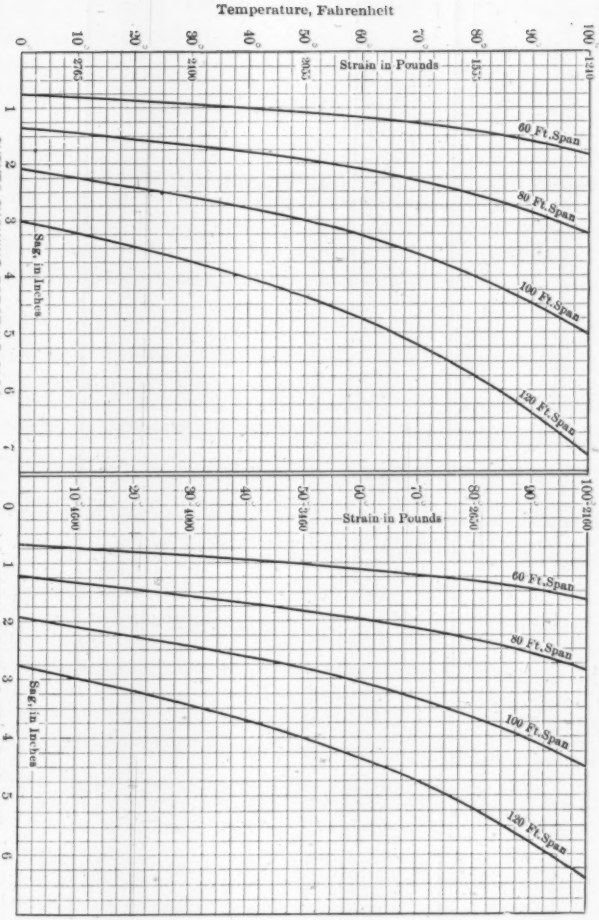
Grounding the Running Rails.—In order to avoid any considerable

potential between the running rails and the ground, it is necessary to provide ground-plates at frequent intervals, with adequate connections between these and the running rails.

Iron and Steel Work.—Most of the iron and steel parts used in catenary construction are small in cross-section. For long life, a preservative coating is necessary. Proper inspection, cleaning, and painting are accomplished with difficulty, and, although such care is essential, there is considerable probability of neglect. A short-lived coating, therefore, is not sufficient. Galvanizing seems to be the only suitable method of protection thus far developed. The combined action of the elements and locomotive gases on galvanized work has been watched carefully. The locomotive exhaust forms a hard deposit on wires placed directly above the center of the track, and this deposit seems to act as a preservative coating over the galvanized surface. In this work there is special necessity for ample thickness of ungalvanized sections, because of the difficulty involved in adequate inspection and painting.

Trolley Wire.—It is essential that the trolley wire shall at all times be under sufficient tension to avoid appreciable sag between the 10-ft. supports. With catenary construction, of the type herein referred to, a tension of at least 2 000 lb. is necessary in order that the pantagraph shoe may ride smoothly under the trolley wire. With lower tension there will be chattering of the pantagraph, and abnormal wear of the pantagraph shoe and trolley wire. If the minimum tension at 100° fahr. is 2 000 lb., the theoretical strain at 0° fahr. will be approximately 5 000 lb., as shown in the curve sheet of sags, Fig. 2. The actual strain will be some indeterminable figure less than this, depending on the general elasticity of the system. The average tensile strength of a 4/0 hard-drawn copper wire when new is 50 000 lb. per sq. in., or 8 310 lb. for a 4/0 wire. The elastic limit is 35 000 lb. per sq. in., or 5 817 lb. for a 4/0 wire. As the copper wire is reduced by wear, the tensile strength is reduced more rapidly than the physical section, because the center is not as strong as the skin. "Phono-electric" wire has physical characteristics which are much better suited to this service, as follows:

Tensile strength: 68 780 lb. per sq. in., or 11 330 lb. for a 4/0 wire;



CURVES SHOWING ERECTING SAGS IN 5/16" MESSENGER CABLE
(BEFORE HANGERS ARE ATTACHED)
MODULUS OF ELASTICITY 21000000

CURVES SHOWING ERECTING SAGS IN 1/0 PHONO-ELECT. TROLLEY
(BEFORE THE TROLLEY WIRE IS PLACED IN HANGERS)
MODULUS OF ELASTICITY 18000000

FIG. 2.

Elastic limit: about 58 000 lb. per sq. in., or 9 640 lb. for a 4/0 wire;

The material is homogeneous throughout;

The material is considerably stiffer than hard-drawn copper;

The wire may be worn to the limit permissible by the hanger fastenings before the strain at minimum temperature will equal the elastic limit of the reduced section.

The conductivity of this material is about 45% of that of hard-drawn copper, but, in alternating-current railway work, this is of less importance than in direct-current work, for several reasons. The track resistance is much higher than with direct current, because of the self-inductive effect of the rails, which are of magnetic material. There is, also, an additional drop in the circuit, due to the induction between the trolley wire and the rails.

Taking all these factors into account, the increase in the combined drop, resulting from the use of this material with low conductivity, is only 38 per cent. Furthermore, as the circuit has to be calculated for the maximum load, and the daily average is a small proportion of this, the increase in the average energy loss is inconsiderable.

In view of the cost of labor and supplies in renewing the trolley wire, and the interference with operation while this work is going on, the advantage of long life is apparent. Therefore, the physical advantages are largely in favor of the phono-electric wire, and the electrical disadvantages which offset these are not serious. This material is used in the Denver and Interurban work.

Splicing Sleeves.—Mechanical splicing sleeves, in which the trolley is bent on short radius, do not preserve the full strength of the trolley wire, as the outer fibers on the bends are strained beyond their elastic limit. For this catenary work, where the higher strains are necessary, as above stated, it is essential that the splicing sleeve, including the ends of the trolley wire connected thereto, shall have the same strength as the main body of the wire. To this end, the wire must enter the splicing sleeve with practically no bends. The best sleeve thus far developed is one of the style indicated in Fig. 3, in which the joint is made with solder.

Trolley Hangers.—The trolley wire is supported from the messenger wire at intervals of 10 ft. The supporting device, or "hanger,"

PLATE XII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXII, No. 1096.
LYFORD ON
CATENARY TROLLEY CONSTRUCTION.

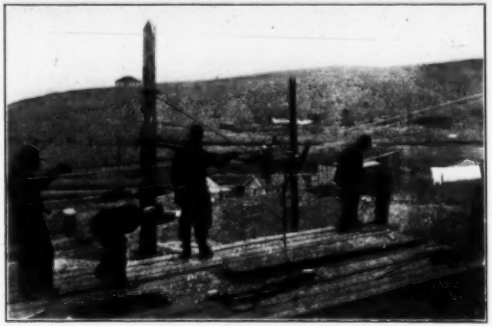


FIG. 1.—PUTTING THE STRAIN ON TROLLEY WIRES.

FIG. 2.—GAUGING THE CATENARY STRUCTURE.

FIG. 3.—COMPLETED CATENARY WORK ON A CURVE.

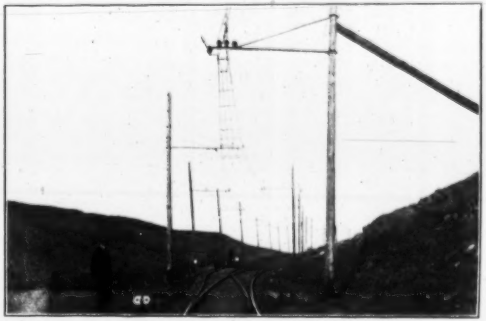


FIG. 4.—TURN-OUT.

varies in length according to the sag of the messenger cable. As many thousands of these hangers are used, it is important that the design be suited to the special conditions of erection and operation. The Denver and Interurban hanger, illustrated in Fig. 4, embodies the following features:

The trolley clamp and hanger rod can be assembled in the work car before erection;

The operations necessary when erecting are such that they can be performed with the utmost speed;

The hanger can be easily loosened, when necessary to pull the slack out of the trolley wire;

It has $\frac{1}{2}$ in. adjustment in length;

All nuts move freely, but lock in position;

It is strong, but light.

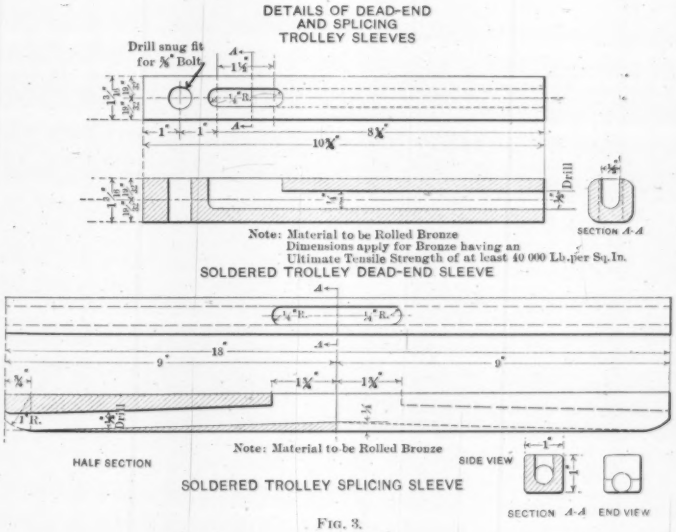


FIG. 3.

Insulation.—An insulation failure on a high-tension electric system means the loss of power over the entire section in which the trouble occurs. This may mean that a number of trains will be brought to a stand-still, and, unless the trouble is quickly located, a considerable

blockade will result. This makes it necessary that high-voltage trolley systems be put up so as to minimize line troubles. This condition has led to exhaustive investigation of different types of insulators and different methods of construction. Porcelain is the best material thus far found for insulating purposes, and, with sufficient factors of safety

ADJUSTABLE TROLLEY HANGER.

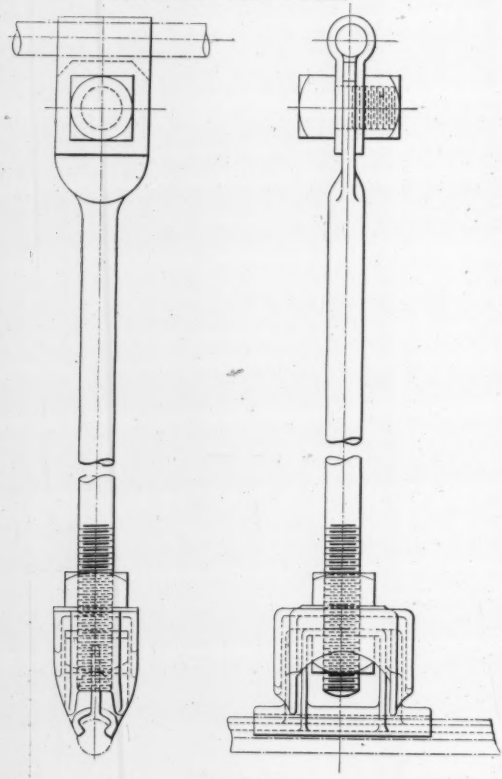
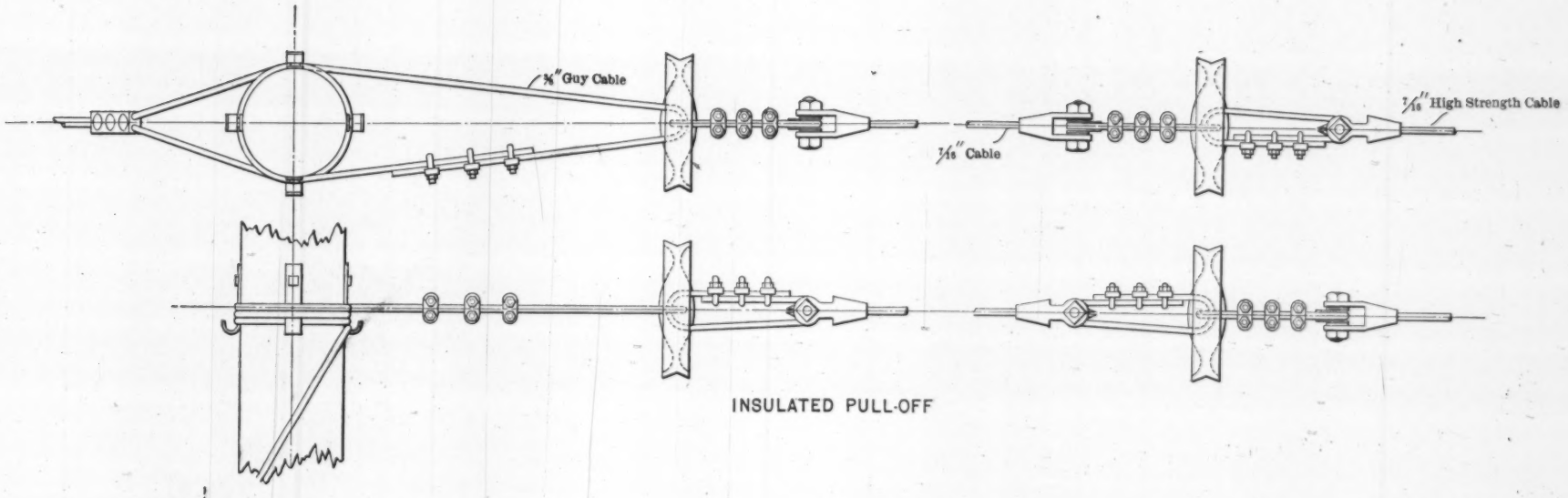
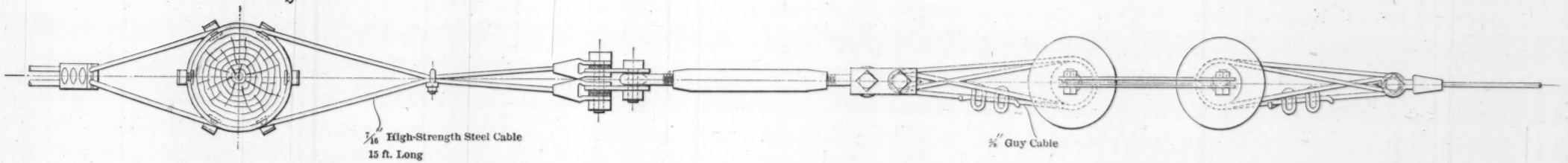


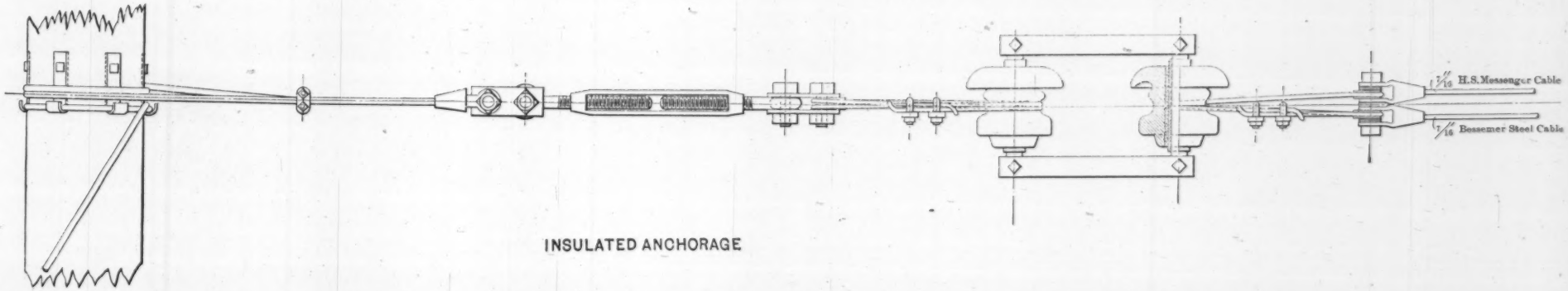
FIG. 4.

against mechanical strain and electrical tension, catenary structures insulated with porcelain have been found very reliable. The insulator used in straight-line work in the present case is illustrated in Fig. 1, Plate XIV. This is a triple-petticoated insulator designed for regular operation at 22 000 volts. Each insulator was tested at the factory



INSULATED PULL-OFF





INSULATED ANCHORAGE

with 70 000 volts when dry and with 43 000 volts when subjected to an artificial rain. The same insulator is used in the "steady strain" described below. For pull-offs, a disc-type insulator is used, as illustrated in the upper part of Plate XIII. This insulator will stand a combined mechanical strain of 6 500 lb., and electric tension of 30 000 volts. For dead-ending work, spool-type insulators are used, as illustrated in the lower part of Plate XIII. These insulators, when properly harnessed, as shown in Plate XIII, can be subjected to a combined test of 14 000 lb. compression and 55 000 volts electric potential. All strain insulators are used two in series so as to double the electrical factor of safety; and the harness is interlaced, so that, should one insulator break, the structure will not fall to the ground, but the remaining insulator will be adequate, electrically, to permit the continuation of operation until repairs can be effected.

Steady Strain.—To keep the trolley wire in a position vertically below the messenger wire on curves, it is necessary to use a special device known as a "steady strain." The construction must be such that in no case will it interfere with the pantagraph trolley. The steady strain must be insulated from the supporting bracket. The insulator and the means of fastening it to the bracket are necessarily heavy, and, should they become disconnected from the bracket, would sag to a position where they would be below the plane of the pantagraph. To provide against this emergency the steady strain used on the Denver and Interurban road is of a new design, and is arranged so that in case of breakage the insulator and the parts attached thereto are automatically released from the member attached to the trolley wire and fall to the ground, thus preventing interference with the pantagraph. This device (Fig. 1, Plate XIV) is inexpensive and effective.

Deflector.—To avoid the possibility of the pantagraph becoming caught in the diverging wires of a turn-out, it is customary to provide an arrangement called a "deflector," consisting of intermediate wires suitably mounted between the two trolley wires. The device used in the case under discussion is illustrated in Fig. 5, and also in Fig. 4, Plate XII, and Fig. 2, Plate XIV.

Cross-Spans.—The cross-span construction for 11 000-volt work of the Denver and Interurban Railroad is illustrated in Fig. 6. The entire structure is grounded for safety.

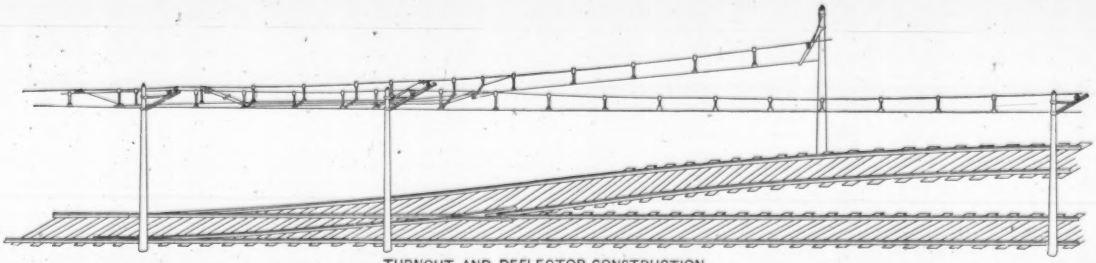
Offset of Trolley Wire.—In the Denver and Interurban work the pole setting on curves has been such as will permit of keeping the trolley wire within 3½ in. of a line directly above the center of the track. The poles were spaced according to the figures in Table 1.

TABLE 1.—POLE SPACING.

Degree of curvature of track.	Pole spacing, in feet.	Divergence of trolley wire from track, in inches.
Tangent.	120	0.
1	120	1.87
2	110	3.37
3	90	3.06
4	80	3.37
5	70	3.06
6	60	2.87
7	50	2.34
8	50	2.64
9	50	2.94
10	50	3.24

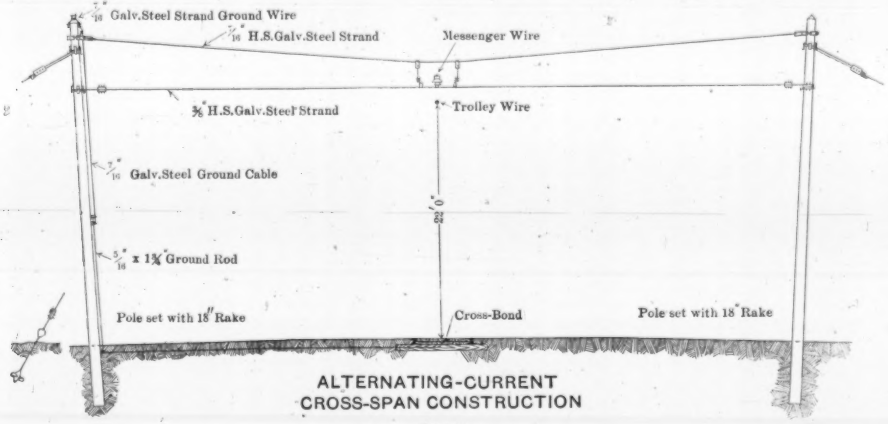
Many roads have used greater offsets than shown in Table 1, in order to save poles, but it should be borne in mind that the use of an overhead conductor in a permanent position above the tracks has a material effect upon existing practice in maintaining roadbeds. Hitherto, the tracks have been constantly shifted by the section men in the correction of the alignment and in ballasting, and there have been no close limitations. With catenary work above the track, the section man is forced to work within close limits. For instance, 1 in. superelevation of one rail means 4½ in. deflection of the pantagraph. If this is a bump in the track and causes the car to sway, the divergence may be considerably more. If this happens on a curve, the deflection of the pantagraph and the offset of the wire act together. Obviously, it will be some time before section men are trained to the necessity of close work, and they should be given as much latitude as possible. This means that there should be as little offset as practicable in the original design. Furthermore, the use of small deflections means a minimum of side strain on the structure, and, therefore, a minimum likelihood of displacement of insulators, steady strains, etc. With wood poles at present prices, adherence to this practice of using small offsets does not materially affect the cost.

Advantage of Light Supporting Structure.—The use of wooden poles for catenary construction is in many respects preferable to the



TURNOUT AND DEFLECTOR CONSTRUCTION.

FIG. 5.



ALTERNATING-CURRENT
CROSS-SPAN CONSTRUCTION

FIG. 6.

use of heavy steel bridges. The principal advantage is in the ease of repair. It is unfortunate for catenary work that the supply of wooden poles is rapidly diminishing. An equally light, but strong, substitute is desirable. The question naturally arises as to what will happen to the catenary structure, if the poles are struck by a derailed train. One answer to this question was given in the case of similar catenary work for the Erie Railroad. A derailment of the work train occurred during the construction period, and the caboose was driven into one of the electric poles. The pole was cut off at the ground line, the insulator torn loose, and the pole thrown to one side entirely free from the catenary work. The tie-wire, by which the messenger cable is attached to the insulator, acted as a safety connection in such a case, as, by breaking, it released the catenary structure from the bracket and pole. With the tensions used in the ordinary catenary structure of the Denver and Interurban, two adjoining poles may be destroyed and the trolley wire will only sag to 17½ ft. above the track in the maximum case.

Sectionalizing the Trolley Wire.—For convenience in locating faults which may develop in the catenary construction, it is advisable to divide the conductor into sections 4 or 5 miles in length. These sections are normally connected so as to make a continuous circuit, the connections being through switches which can be opened for test.

Clearance of Overhead Obstructions.—The proper height for the trolley wire above the running rail is 22 ft. This means a standard height of 24 ft. for the clearances of through and under bridges, and still greater clearances for other overhead obstructions wherever physical conditions permit. In a large majority of cases, new construction can be designed for 24 ft. clearance without much difficulty or material addition to cost. It is recommended that railroads adopt this as the standard height for clearances in the future, except for tunnels, municipal bridges, etc., where other conditions govern. For clearances of less than 24 ft. special constructions of the catenary work have to be provided, which are more or less objectionable.

Hard Spots in Catenary Structure.—For high-speed operation, it is essential for satisfactory operation of the pantagraph that the maximum flexibility of the overhead structure be maintained at all points. For this purpose, it is important that heavy weights and hard spots be kept out of the system wherever possible.

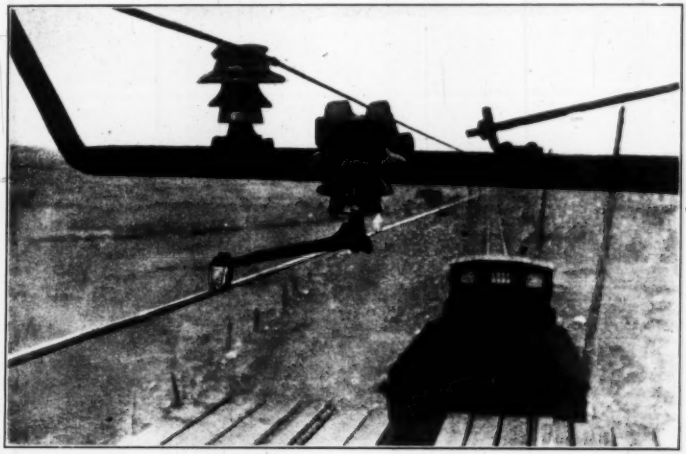


FIG. 1.—LINE INSULATOR AND STEADY STRAIN.

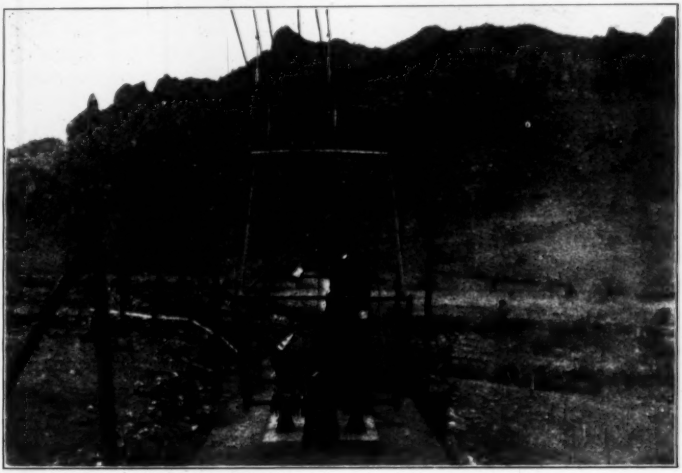


FIG. 2.—DEFLECTOR.

Bonding.—Experience with the numerous types of bonds which have been placed on the market indicates that wherever possible the bonds should be placed under the splice-bar. Bonding the tracks of a road which is in constant use is a difficult and slow operation with bonds of this type, but the advantage to be gained in the way of permanence and security warrants the trouble.

Repair Work.—In view of the fact that line trouble usually means loss of power, the work train cannot be taken to the fault by an electric locomotive; therefore an independent unit should be provided, that is, either a steam locomotive or a gasoline car, preferably the latter, because the stand-by losses on such a car are small, and it can be quickly put into service.

Power Supply.—The power for operating the cars of the Denver and Interurban Railroad is furnished by the Northern Colorado Power Company from its power-station near Louisville. For this purpose, two 1 000-kw. single-phase turbo-generators are provided. Two feeders connect this power-station with the center of distribution at Louisville Junction. The switch connections at Louisville Junction are such that both feeders may serve all three legs of the trolley simultaneously, or one feeder may serve the main line and the other feeder serve the two branches (Fig. 1). Single-phase generators necessarily cost considerably more than generators designed to deliver the same output into a three-phase system, and in some cases it is preferable to generate three-phase current and serve separate sections of the trolley line from each of the three phases. As a general rule, however, where new generating equipment is provided for single-phase operation exclusively, the advantages are in favor of the single-phase generation, even at the increased cost.

Telephone and Telegraph Interference.—Single-phase current has an inductive effect on parallel telephone and telegraph circuits, causing interference with the operation of such circuits unless special protective means are used. Simple devices have been contrived for overcoming this interference, so that there is now but little difficulty with the operation of such parallel circuits. In most of the single-phase roads there is a telephone system on the same poles as the trolley line, and, with proper transpositions and suitable means for removing the induced charge from the telephone line, it operates very satisfactorily and without shock to the operators.

Cost.—The cost of this catenary construction varies between rather wide limits, depending on the amount of electric train service to be operated, the physical conditions as to curves, grades, obstructions, and pole foundations, and the amount of traffic on the line during electrification. These conditions affect the cost of both material and labor. The labor operations mentioned in this paper are those performed under most favorable conditions. It has been found that, because of conditions beyond the control of the designer or the construction crew, the amounts of work per day may be cut to one-third, or even as low as one-seventh, of the figures given herein. In general, it may be said that, under favorable conditions, 11 000-volt catenary construction on wooden poles, with conductors sufficient for a half-hourly operation of two-car trains, and including track bonding, costs from $3 500 to $5 000 per mile of single track electrified.

DISCUSSION

JOSEPH MAYER, M. AM. SOC. C. E. (by letter).—This paper ably presents the results of the latest, practical, American experience with catenary trolley construction. The main features of the line described are: A 0000 phono-electric contact wire of one and two-thirds times the elastic limit of the best hard-drawn copper wire, with 2 000 lb. tension, at 100° fahr., 120-ft. spans of the carrying ropes on tangents, and shorter spans on curves, and solid round hangers 10 ft. apart. Mr. Mayer.

By calculating the bending strains and tensions in the contact wire, the writer has reached, and published, the conclusion that a really safe catenary suspension for high speeds is impracticable with a copper contact wire without introducing adjustments of the length of the wire to balance the effects of changes of temperature. The large bending strains and tensions in the contact wire cause the practical failure, with high speeds, of the older catenary suspensions. In the United States, the remedies are the use of a stronger wire, and, in some cases, of a supplementary wire, and of short spans of the carrying ropes; in Europe, a supplementary wire and complicated adjustments for changes of temperature are used. The supplementary wire of the German Siemens-Schuckert suspension carries the contact wire in loose loops, and secures, without excessive tension in the contact wire, on the regular line, an approximately straight motion of the current collector. The jumping of the latter is thereby avoided.

For obtaining continuous contact at high speed, the usual single-wire catenary suspensions require a light current collector and a large minimum tension in the contact wire. With a drop of 140° in the temperature of the wire, this tension, with a copper wire, is increased about 21 000 lb. per sq. in. The deflections of the wire produced by the wind pressure, the pressure of the current collector, ice loads, and changes of temperature, result in another increase of the tension, and, at the steady strains especially, in considerable bending strains. The maximum strain in the wire, therefore, exceeds the elastic limit of the best copper wire. Since the bending strain in the wire is inversely proportional to its least radius of curvature, it can be reduced by making the wire bend in curves of long radius; since the tension, with a given span, is inversely proportional to the sag, it can be reduced by increasing the sag. This has suggested to the writer a new method for obtaining a safely suspended wire, namely, by suspending it, with a large sag, from such hangers as will make it bend in curves of long least radius. The large sag gives a simple automatic adjustment for changes of temperature, because the wire can shrink on account of cold, with reduction of the sag, and without excessive increase of its tension. By such a suspension of the contact wire

Mr. Mayer. from a tapering steel bar, 6 ft. 7 in. long,* and by omitting the carrying ropes and the intermediate suspenders, the tensions and bending strains in the wire, with 120-ft. spans, can be reduced to less than one-half the amounts resulting from catenary suspension with the same span between the main supports. The current collector, instead of oscillating rapidly, will then move up and down slowly in long shallow waves. The reduction of the contact pressure, due to centrifugal force at high speed, is then trifling and its increase moderate, and the latter occurs under the hangers where the wire is reinforced by them. A small static contact pressure, with reduced wear of the wire and the current collector, becomes thereby practicable. This suspension is equally suitable for trolley wheels and sliding bows, while catenary suspensions are not well adapted to the former. With 0 copper wires, 220-ft. spans give a safe suspension, requiring current collectors 7 ft. long; with phono-electric wires of the kind described by the author, 300-ft. spans with an average sag of 3 ft., can be used safely on tangents. The loads and wind pressures per linear foot carried to the brackets are about one-third of those with single catenary suspensions. Poles and brackets of 120-ft. catenary spans are adequate for the 300-ft spans of the new suspension. Curves call for the same hangers and shorter spans, but, on account of the reduced tension and wind pressure and the consequently diminished side pull, much longer spans than those used by the author become practicable.

Mr. Lyford states that for high-speed operation the maximum flexibility should be maintained at all points, and that heavy weights and hard spots should be kept out of the system wherever possible. What is here called for is impossible and unnecessary. An accurate definition of what is really needed is of much importance for obtaining a good track for a high-speed current collector.

The line should be built so that the current collector will move in curves of long least radius. With sliding-bar collectors, the vertical curvature of the motion of the collector is alone important; with trolley wheels its horizontal curvature must be equally considered. The collector exerts a normal pressure on the contact wire; this should be as uniform as possible. The centrifugal force arising from the curved motion of the collector and of the rigidly connected parts of its supporting frame produces an equal variation of the contact pressure. Where the motion of the collector is convex upward, the contact pressure is increased; where it is convex downward, it is decreased. In the former case excessive bending strains in the wire and large local wear of it may result; in the latter, there may be interruption of contact and consequent sparking. The excessive curvature of the motion of the collector may arise from too much flexibility of the contact wire; it will often arise from a sudden change in

* One form of such a bar is shown in *Transactions*, Am. Soc. C. E., Vol. LXI, p. 31.

flexibility. A weight moving in a curve produces a centrifugal force, Mr. Mayer.
$C = \frac{W v^2}{32.2\, r}$, where W is the weight, v the velocity, in feet per second, and r the radius of curvature of the motion, in feet. The current collector and parts of its rigidly-connected supporting frame do not move in the same manner, the radius, r, being variable. The weight, W, which produces, when moving like the contact point, the same centrifugal force as the collector and its frame, is called the equivalent weight. This equivalent weight and the radius, r, of the curvature of the motion of the contact point determine the variation of the contact pressure due to centrifugal force. The radius, r, depends largely on the design of the overhead line, but is also influenced by the static contact pressure and the size of the product, Wv^2. An overhead line is only safe and adequately smooth up to a certain maximum value of this product, therefore, this must be known in order to judge as to the adequacy of the line. The value of r must be calculated from the nature of the overhead line and the given value of the static contact pressure and of the product, Wv^2. To neglect the calculation is to incur risk of failure, unless the safety of the design and the smooth running of the collector can be inferred from previous experience, similar or less favorable in all essential points. Catenary suspensions make no satisfactory provision for harmlessly changing the direction of the overhead line and of the motion of the current collector. Such change is unavoidable at the main supports and, to a larger extent, at low overhead crossings and tunnels where the line must be lowered and raised. Sparking or excessive contact pressure and large bending strains in the wire generally result from high speed at these points. They are weak spots, and are rarely mentioned in descriptions. On the regular line the sharpest curvature of the wire and of the motion of the collector, in the author's design, occurs near the hangers and steady strains. In this design, the wire has 10-ft. spans, with the ends nearly fixed in direction. If the wire were practically hinged at the hangers and the steady strains, these bending strains and curvatures, and the consequent risk of jumping of the collector at high speed, would be greatly reduced. Hangers made of flat bars, $\frac{1}{8}$ in. thick, with proper end connections, which are used on some lines, provide practically hinged clamps for the wire; they are preferable, therefore, for high speeds. With a light current collector and moderate speeds, this defect of the hangers used by Mr. Lyford can be partly neutralized by using a larger minimum tension in the contact wire than would otherwise be required. This will give smooth running of the collector, but will result in larger tensions and bending strains in the wire and larger side pull on curves. The current collector raises an advancing wave in the contact wire. The wire in front of the collector turns up and rises; in the rear, it turns back and

Mr. Mayer. falls. If the clamps holding the wire were light and if each was connected to its hanger by a horizontal bolt, normal to the wire, passing through a slotted hole, permitting the clamps to turn and to rise when the collector passes, the hangers would not prevent a practically straight motion of the collector, and chattering would be avoided with the highest speeds and with moderate tension in the contact wire.

This remedy is impracticable at changes of vertical slope. The wire carries a part of the wind pressure and some vertical shear to the steady strains and is subjected to consequent bending strains. These become large with long spans and compel the use of short spans. If the steady strains are replaced by flexible, tapering bars holding the wire under them, these bending strains and sharp vertical and horizontal curvatures of the contact wire are reduced to small amounts, and long spans become safe. A 0000 phono-electric wire suspended from a steel-wire rope with a diameter of $\frac{3}{4}$ in., the former with 2-ft., the latter with 5 ft. 6 in., maximum vertical sag, gives, with 300-ft. spans, with proper hangers and with flexible bars for steady strains, a safe catenary suspension for the highest speeds, suitable for sliding bows.

The flexible bars also furnish a satisfactory means of overcoming all difficulties arising from irregularities of the line at tunnels and overhead crossings. Such long spans are heavy and exposed to large wind pressure; they would have to be carried by substantial steel or reinforced concrete posts with concrete foundations.

If a wire is hung, without carrying ropes, in straight rigid clamps, it is bent sharp at their ends. To reduce these bends and the consequent blows at high speed from the current collector, short spans and small sags of the wire become necessary. If, instead of a rigid clamp, a long flexible bar is used, the wire being attached all along the bar, and the bar being of such shape that it will bend vertically and horizontally approximately in circles, then the radius of least curvature of the motion of the collector becomes very long, and long spans with large sags can be used. Any desired change in the direction of the wire can be made by using such bars without large bending strains in the wire or excessive contact pressure. All irregularities in the line, which, in most suspensions, are the most serious sources of trouble, can be provided for satisfactorily. It can be easily shown that the cost of construction and maintenance of safely suspending the contact wire by such flexible hangers is only about half as much as with safe catenary suspensions.

For a certain maximum value of the product, Wv^2, not stated by the author, the design described by him gives, with adequate poles and brackets, a safe and suitable suspension for curves and tangents. No information is given for other irregularities of the line. Wherever the value of the product, Wv^2, is small enough to give smooth running of

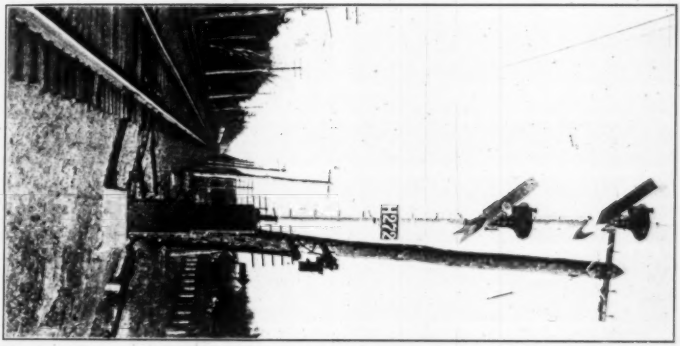


FIG. 1.—THE RELATION BETWEEN SIGNALS AND POLES.

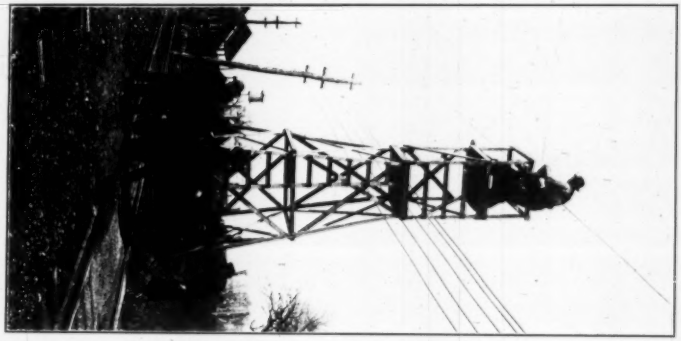


FIG. 2.—LIGHT TOWER, ON GRAMPUS.

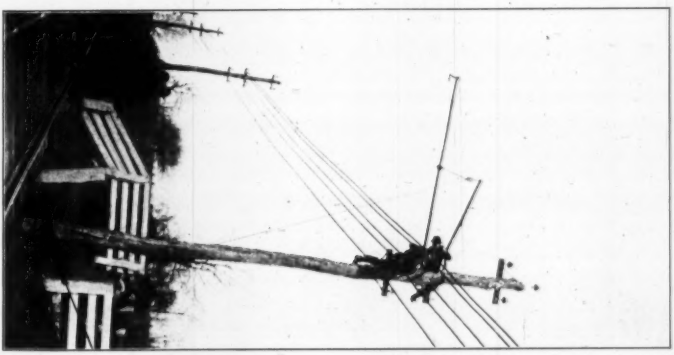


FIG. 3.—BRACKET HOIST.

the current collector, Mr. Lyford's design is decidedly preferable to the Siemens-Schuckert suspension, which is more complicated and more expensive to construct and maintain. The safe value of the product, Wv^2, and, therefore, the limits of usefulness of the design have evidently not been determined by the author. Mr. Mayer.

In the writer's opinion, the introduction of carrying ropes and numerous hangers to suspend the wire at short intervals in an approximately straight line is a mistake. It complicates the design, calls for short main spans and a very strong large wire, and it produces a rapidly oscillating and sharply curved motion of the current collector with consequent large variations of the contact pressure. The suspension, therefore, is unnecessarily expensive to construct and maintain. These complications were introduced to remove the sharp bending of the wire at the ends of the hangers. This can be more easily and efficiently accomplished by spreading the bending uniformly over a sufficient length of the wire. The amount of curvature at the ends of the hangers with a given span and sag is extremely variable. It depends on the wind pressure, the pressure of the current collector, the ice load, and the temperature. The long transition curve at the hangers, therefore, must also be variable, and it can only be simply produced by connecting the wire to a long elastic bar. To make the bar curve uniformly, it must have cross-sections decreasing in a suitable manner from the center toward the ends. Calculation shows that a nickel-steel bar consisting of two truncated cones and a short central cylinder, is both sufficiently strong and flexible to meet all requirements of high-speed operation on curves and tangents with an ample factor of safety, and to give, at the time of maximum tension, small bending strains in the wire. With the long spans thereby made possible, the current collector does not lift the wire above its supports; it therefore diminishes its main curvature, except under the hangers. With the frequent hangers of the catenary suspensions, the wire is lifted above the supports, and the collector moves in short waves. To judge the radii of curvature of the long and the short waves, it is well to consider the heights of waves of different lengths having the same radius of curvature. These heights are as the squares of the lengths. Regular waves, 300 ft. long and 48 in. high, have the same curvature as waves 10 ft. long and 0.0533 in. high. The motion of the collector with the suspensions here considered is in both cases a very irregular wave motion; the above equivalent heights give, therefore, only a roughly approximate idea of equivalent deflections of the wire for the two kinds of suspension. An impracticable tension of the contact wire would be needed to limit the height of the small waves to the amount above given. The comparison clearly shows that a large sag of the wire with long spans is not necessarily an obstacle to the smooth running of the collector at high speed, and to small variation

Mr. Mayer. of the contact pressure. It also shows that the vertical alignment of the numerous supports of the contact wire must be very accurate to avoid large increases in its curvature and in the variation of contact pressure at high speed. With the long spans an error of 6 in. in the position of a hanger produces but small additional strains in either the wire or the hanger. The erection of the long spans, therefore, requires little accuracy; 300-ft. spans, with phono-electric wires, require a maximum deflection of 4 ft. and a nearly corresponding variation of the height of the current collector. If this is objectionable, 200-ft. spans with 2-ft. sag can be used. With these shorter spans, a sliding bow 4 ft. long is adequate. Heavy weights in the line are not harmful if provision is made that they will not cause sharp curvature of the motion of the current collector. A modification of the flexible bar here proposed can always be adapted to achieve this end. A line safe for high speed through its whole length becomes thereby practicable.

The advantages of long spans between main supports are especially conspicuous where wooden poles stuck into the ground are not considered a sufficiently substantial and durable carrying structure. When concrete foundations and creosoted poles are used, the first cost of the supports is greatly increased, and the saving of half of them becomes immediately important; and still more so where steel or reinforced concrete poles are used. In such cases still longer spans are desirable; 352-ft. spans give an amply safe structure with a 00 galvanized-steel contact wire. The risk of damage by derailments is greatly reduced by the use of fewer supports. A flexible bar suspension requires only one kind of hangers, brackets, and poles, and the number of spare parts needed for quick repairs, therefore, is small. The small number of supports allows the choice of substantial and durable ones without excessive cost of the line.

Mr. Harte. CHARLES RUFUS HARTE, M. AM. SOC. C. E.—The successful operation of a number of heavy-service electrified lines, together with returning financial confidence, indicate that further development in the direction of such electrification is almost certain, and make this paper most timely, particularly as there yet remains to be spoken the last word on the distribution and collection of electric energy in large quantity and at high speed.

The author's record of electrification of steam roads will apparently bear slight correction: In view of the pioneer work of Colonel N. T. Heft, it would seem desirable, in recording the New York, New Haven and Hartford Railroad electrification, to note the third-rail installation between Hartford and New Britain. The electrification of the West Shore Division of the New York Central (unless the speaker is greatly mistaken) is 600 volts, third-rail, and not overhead trolley.

The overhead construction on an electrified line is one of the very

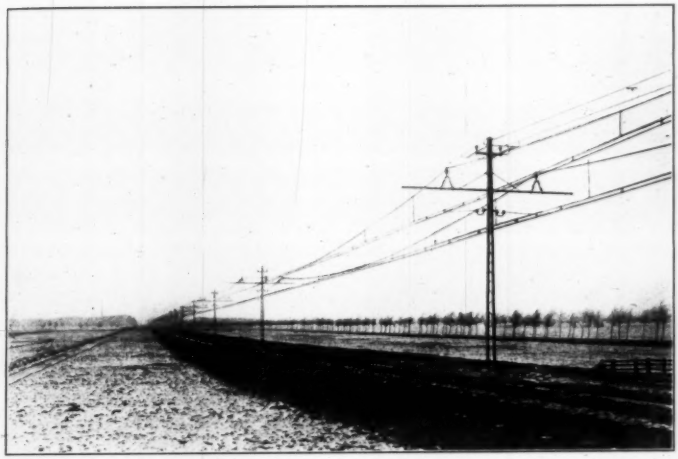


FIG. 1.—SIEMENS-HALSKE COMPOUND CATENARY, ROTTERDAM-HAAG-SCHEVENINGEN LINE.

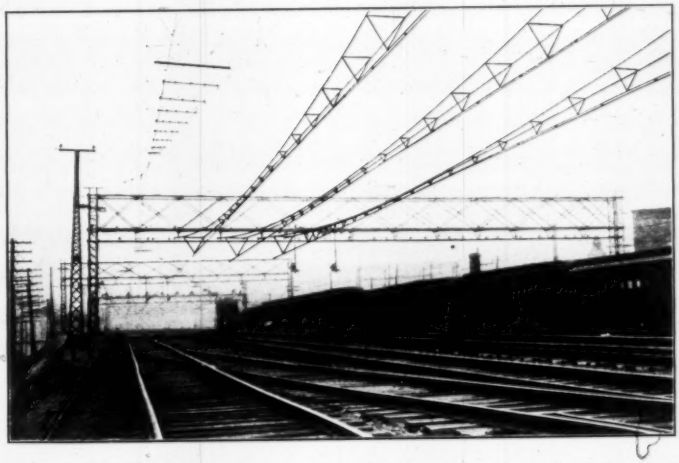


FIG. 2.—COMPOUND DOUBLE CATENARY, N. Y., N. H. & H. R. R., NEW YORK DIVISION.

important features, for a failure on its part is most unfortunately apparent. Delays on a steam road, affecting as a rule but two or three trains, are passed over by the public as inevitable, but a failure of the overhead of the same line when electrified, with the consequent paralysis of traffic in the affected section, calls down the severest criticism, although the aggregate monthly train minutes of delay in the latter case are almost invariably far less than for the corresponding period under steam operation. Mr. Harte.

Not only in its general relation to the line is the overhead a critical feature. As Mr. Lyford clearly points out, the fact that it is not easily reached for inspection necessitates a class of work that will stand up satisfactorily under neglect; and this is particularly true when, as is apparently the case on the Denver and Interurban, a large portion of the line is fed directly through the trolley. The overhead, therefore, should be of the best, as regards both material and labor, and should be of such a design and character that failures are reduced to a minimum and the necessary repairs can be made with the least possible interference with operation.

This relation to operation, too, will usually be found the controlling factor in installation. Where the work train can have a reasonably clear field, a derrick car is decidedly economical for pole setting, but where there are many train movements, particularly if these are largely freights, not on regular schedule, the cost of delays on sidings will frequently be found to more than offset the mechanical gain. The lay-over loss can be reduced by using the derrick merely to pick up and place in the holes the sticks, the final setting being made with pikes while the derrick is "bottled up," but the danger of an untamped pole toppling toward and fouling the track makes the economy questionable.

The clearance of 8 ft. 6 in. from track center to pole face seems scanty. Present-day steam road practice favors at least 10 ft. as clearance distance, and this is essential to good sighting of signals, a very common location for the latter being with mast 8 ft. from rail, in which case the spectacle is in line with a pole set 8 ft. 6 in. from the center line. Moreover, with a pole spacing of 150 ft., and the poles at all near the track, there is, at high-speed operation, the optical effect of a narrow lane to which the vision of the engineer is restricted. The plan of pivoting the signal blades at the center instead of at the end assists the view materially, and has been followed on several electrifications. Aside from the question of signals, the tendency of track gangs to shift the track bodily in lining up, particularly at curves, makes it very desirable to have a little more leeway than is given by the clearance on the Denver and Interurban.

For the installation of the catenary itself some form of work train is of course a necessity, and it is desirable that this be at least the

Mr. Harte. length of the standard span. The entire span can then be installed at one setting of the train, and on close multiple-point suspension there is given no opportunity for the aggravating interchange of hangers of slight difference in length. On the New York Division electrification of the New York, New Haven and Hartford Railroad, flat cars were used, a series of towers being built upon them; here the hangers are 10 ft. apart. On the Midland Division electrification, where the hangers are 50 ft. apart, single towers were largely used, an overhang giving access to brackets. On the Berlin-Middletown-Meriden-Westfield simple suspension, the contractors, Messrs. Latey and Slater, used a regular tower car where there was little traffic, but between Middletown and Berlin, where shuttle trains kept the line hot, there was successfully used a light tower on a grampus which could be taken bodily off the track to pass trains. Brackets were erected by a simple device consisting of a pipe arm carrying the hoisting tackle and having a jaw to fit the pole, together with a galvanized-strand guy which slipped over the top of the pole. One man could readily place this, after which, by the attached tackle, ground men hoisted the heavy bracket arm and held it while it was being installed. On this line the feeders were run out by the derrick car, a sheave at the end of the boom delivering the heavy cable on the cross-arm very successfully.

As to what can be done with such methods, not much can be said that is of any value in another case. Under favorable conditions, an astounding amount of work can be done in one day, but the conditions may be counted upon to be varying somewhat in degree, and are always unfavorable.

In using a trolley wire of greater abrasive strength than copper, the author takes a step in the right direction. Joseph Mayer, M. Am. Soc. C. E., some time ago suggested the use of a mild-steel contact rod,* to be fed from the copper distribution system, and the compound catenary on the New York Division of the New Haven follows this general plan, the intermediate messenger of copper feeding a trolley of high resistance to abrasion and low conductivity. In the latter installation, by hanging the contactor from points midway between the primary hangers, using clips which grip the contactor but slide on the messenger, there has been obtained the elasticity of the Siemens-Schuckert compound catenary with a much simpler design. The results, apparently, are extremely satisfactory.

It is interesting to note the high tension used in the Denver trolley, and, particularly, the very high initial stress, which closely approximates the breaking strength of 0000 copper trolley in the brazes (6 000 lb.). The speaker specifies that 0000 trolley shall be pulled to a sag of 3 in. for 100-ft. spans at 60° fahr., and on several occasions too-

* *Transactions*, Am. Soc. C. E., Vol. LVII, p. 484.

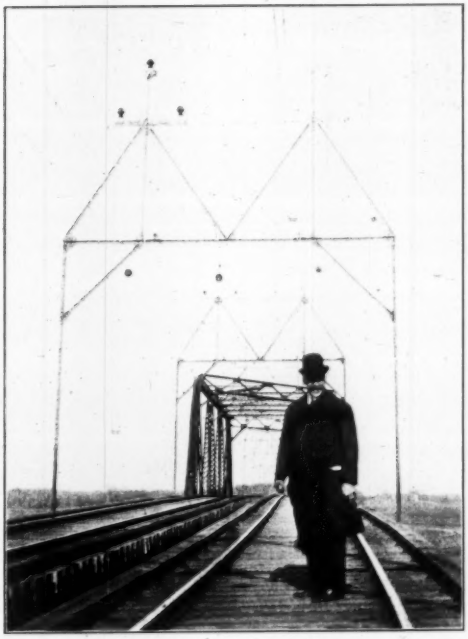


FIG. 1.—ANGLE-IRON BRIDGE,
SYRACUSE, LAKE SHORE AND NORTHERN RAILROAD.

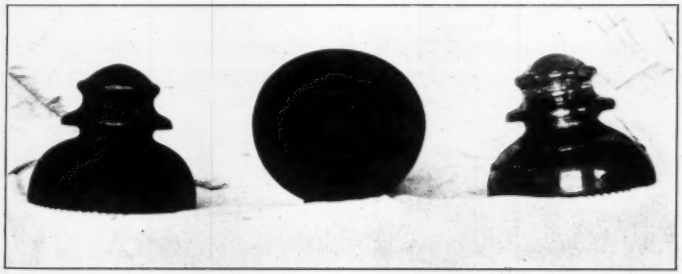


FIG. 2.—SMOKE COATINGS ON INSULATORS FROM RAILROAD RIGHT OF WAY,
INSULATOR AT RIGHT UNCOATED.

enthusiastic line foremen have parted the trolley at a braze. This weakness at the braze, however, acts as a safeguard to the body of the trolley, parting before the elastic limit of the latter is reached, and as the brazes in ordinary 0000 wire are not more than 325 ft. apart, the cumulative resistances of the supports have little opportunity to be large between brazes. Mr. Harte.

Theoretically, the high pulling stresses used in temperate weather should result in extremely severe stresses in winter, but Mr. Lyford's experience has been that of others who have pulled trolley flat in warm weather. As long as the tangents are not extremely long or the trolley anchors are not too rigid, the contraction stresses are very largely absorbed by the yield of the poles.

The splicing sleeve and special dead end (Fig. 3) are doubtless excellent, but the question naturally arises: Why not one of the market types of soldering sleeves for the first, and an eye turned in the trolley itself for the second, rather than special material?

It is the hanger, however, which really opens up the critical question: uniform characteristic of line. The trolley is a track as well as an electric conductor, and as soon as car speeds exceed 30 miles per hour the former function becomes by far the more important. Unquestionably, the absolutely rigid conductor, if smooth, would give ideal conditions, but, up to the present time, the successful development has been in the direction of the flexible type.

It is a question whether the hanger shown by the author will not by its weight cause hard spots and consequent pantagraph troubles. There is a critical speed for any type of pantagraph and hanger spacing at which chattering of the former is harmonic with the time value of the latter. Under such conditions, the blows of the pantagraph increase in violence until they lose step with the impulses, when they die down, leaving the trolley kinked at each hanger. After a number of repetitions the trolley breaks. Incidentally, on alternating-current systems, the rapid make-and-break contact tends to set up surges of tremendous energy.

To obviate the hardness at the hanger, there have been devised flexible-strand hangers, hangers sliding on the messenger, clips sliding on the hanger stem, dash-pots, and spring connections between hangers and clips. The most satisfactory kind known to the speaker is the compound type devised originally by the Siemens-Halske Company, of Berlin. As built by this company, a main messenger carries from flexible-stranded wire hangers a secondary messenger to which the trolley wire is hung by short and frequent loops which allow the trolley to rise without lifting the entire system, and at the same time permit the operation of the compensators which maintain constant tension. The New Haven's modification has screw clips rigidly connected with the trolley and free to slide on the intermediate messenger, and relying

Mr. Harte. on the yield of the intermediate to give the desired flexibility, the clip coming midway between hangers, but not rising on the intermediate messenger.

The speaker would like to know what, if any, troubles have occurred from smoke deposits. Insulators close to railroad tracks condense the locomotive exhaust, which is always more or less oily; the wet surfaces gather carbon and other dust from the smoke, and with the carbonizing of the oil because of current leakage there is formed a coat unaffected by wind or water, which lessens the capacity of the insulator very materially. Dr. Perrine, in 1904,* noted that transmission lines were largely abandoning railway rights of way as locations, for this reason; and the effect upon catenary insulation, so much closer to the source of trouble, should be, and undoubtedly is, correspondingly worse. The speaker knows of one installation where a shield has been placed beneath the insulator, but it is rather too soon to determine with what success.

The steady brace shown is excellent of its kind, but the speaker prefers a pull-off having a flexible strand. Such a pull-off can be attached to the down-curved end of the bracket if the curve is of large radius, but is preferably fastened to a bridle strung between the poles, which latter must then be on the outside of the curve. It is essential, however, that the hanger rod be sufficiently strong to stand the strain. Certain early types of hanger were deficient in this respect, and on sharp curves bent badly. On light curves it is undesirable to use small sizes of wire, but the strand used for sharper curves is so heavy that there is unpleasant sagging. Mr. Gillette, of the Washington, Baltimore and Annapolis, has cleverly overcome this difficulty by splitting the ¼-in. seven-strand cable for 4 or 5 ft., serving the main wire with one of the strands and leading one-half of the remaining strands to the top of the hanger and the other half to the bottom.

The speaker would like to know why the cross-span was put in in catenary instead of simple suspension.

The close-pole spacing on curves, to secure minimum deflection, is much to be commended, and the point that the track is tied to place by the poles is well taken, particularly with such scant clearance as in this case. Not only does a large deflection throw the wire well away from the center of the pantagraph, but the inclination of the latter, due to the curve elevation, gives a powerful horizontal thrust which tends to push the trolley still further away, with likelihood of actual movement off the pan.

At present the speaker knows of no entirely satisfactory substitute for wooden poles, but developments in steel bridges and steel poles, in connection with long spans, promise much. One of the most interesting of the pole types is being investigated and developed, but is not quite

*International Electrical Congress, St. Louis.

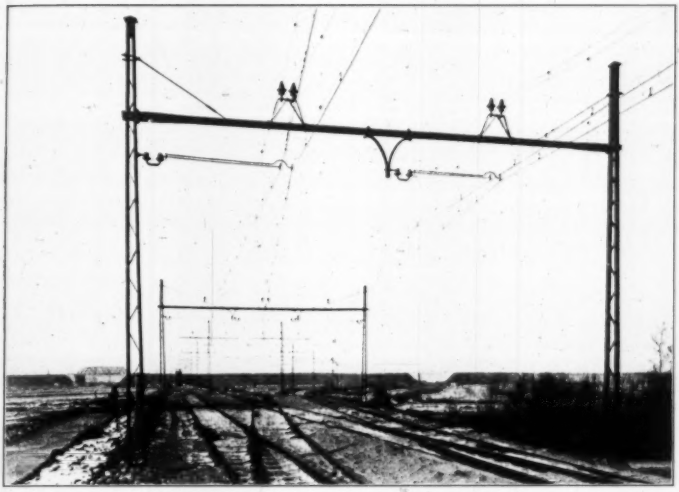


FIG. 1.—SIEMENS-HALSKE LIGHT STEEL BRIDGE, ROTTERDAM-HAAG-SCHEVENINGEN LINE.

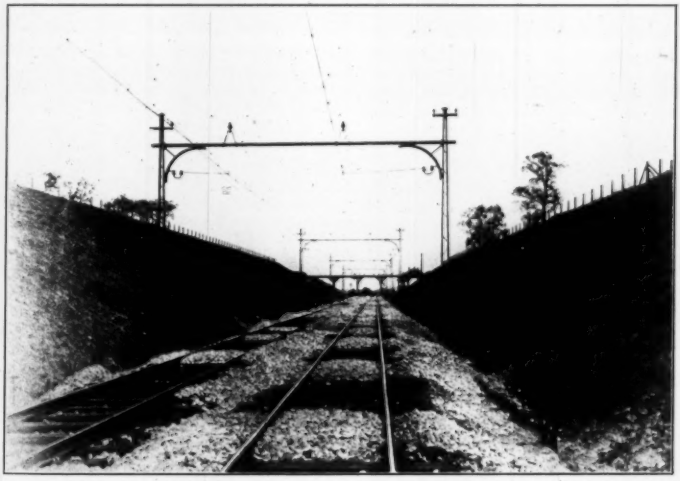


FIG. 2.—SIEMENS-HALSKE LIGHT STEEL BRIDGE,
BLANKENESE-ALTONA-HAMBURG-OHLSDORF LINE.

ready to be placed on the market. Of the types actually in service, the Archbold-Brady bridges, of the Syracuse, Lake Shore and Northern, have proved very satisfactory. These bridges, of channel and angle sections, carry 300-ft. spans of heavy single catenary for double tracks. It has been stated that the cost of bridges, including concrete foundations, was only $800 more per mile than standard wooden pole construction. On the same line, frames made from angles back to back were used on a viaduct. Although these were satisfactory after the catenary was installed, the structure was very flexible before it was tied to the messengers, and it is said that there was considerable difficulty in getting men to work on them. Mr. Harte.

Abroad, the Semenza transmission lines are carried on poles of angles, back to back, while the Siemens-Schuckert catenary installations have had very interesting developments in the way of bridges and bracket poles of light section. The Lancaster Branch of the Midland Railroad, of England, also has a bridge which is of the same general type. It would seem, therefore, that further development might bring out a design of low enough cost to compete successfully with wood, particularly in view of the high maintenance cost of the latter.

While it will be generally agreed that 24 ft. head-room under bridges is most desirable for electrification work, the extra 2 ft. will hardly be secured in New England without heavy expense, even in the open country, while, in the more thickly settled portions, property damage offers a most serious bar. By setting 24 ft., however, for the standard, and working as nearly to this as possible, one of the serious overhead problems will be materially simplified.

W. K. Archbold, Esq.—The speaker has been much interested in this paper, as he has had to meet problems of the same class. He agrees with the author that a reasonable-priced substitute for wooden poles for catenary work is desirable, and believes that steel construction can be provided at a sufficiently low cost. Catenary and transmission-line work require poles of large sizes and of good quality, and it is difficult to procure such poles in large quantities. Mr. Archbold.

The cost of renewals of wooden poles is likely to be a serious element in maintenance in the near future. The speaker is familiar with two roads, not yet four years old, where sawed-pine poles were used, and about half the poles have either been renewed or will require renewal in the near future. The cost of such renewals, especially where high-tension lines are also carried, is of course high and the work dangerous. Timber is becoming scarce, and, while chestnut poles seem to have longer life in the North, they are usually crooked and are also growing scarce.

In discussing Mr. Coombs' paper,* the speaker described some single catenary construction on bridges 300 ft. apart, on the Syracuse,

* *Transactions*, Am. Soc. C. E., Vol. LX, p. 547.

Mr. Archbold. Lake Shore and Northern Railroad near Syracuse, N. Y. While it is now decided that the road is to be operated permanently by direct current with wheel trolleys, instead of 6 600-volt, single-phase current, as first planned, the bridges and catenary construction are to be used for a 14-mile extension to Phœnix and Fulton. The bents on the bridges have been lightened somewhat, the trusses remaining practically as before described.

For a comparison of cost, the speaker would call attention to Fig. 1, Plate XIX, showing standard wooden-pole construction on double-track road, as specified by T. H. Mather, M. Am. Soc. C. E., under whose direction the catenary construction has also been erected. The wooden construction is cross-span, using not less than 35 ft. 8-in. top poles, with a standard spacing of 85 ft. on tangents.

Fig. 2, Plate XIX, shows a catenary bridge construction. Based on item prices and records, the additional cost of the bridges and catenary trolley over the actual cost of the standard wooden construction shown, with ordinary trolley, is $800 per mile of double-track road.

In addition to the statement made by the speaker in discussing Mr. Coombs' paper, it can still be said that, thus far, there has been absolutely no difficulty from side sway on the 300-ft. spans. It was stated at that time that there was yet doubt as to whether or not the line would prove to be too stiff in the vertical plane. There was some difficulty in the hot weather, and it was observed that a part of the line on which the hangers were spaced at 20-ft. centers as an experiment worked better than where they were placed at 10-ft. centers. It was determined, therefore, to go one step further, and that the new construction should have the hangers placed at 30-ft. centers, and that enough hangers should be taken off the first section to give them the same spacing. Experience proves that this is much better. Standing on the rear platform of the car, and holding the trolley rope, a considerable chattering could be felt when the spacing was 10 ft., and, with a heavy car, considerable arcing could be observed at the trolley wheel. With the 30-ft. spacing, a slight rise and fall of the trolley wheel can be noticed by holding the rope, but there is no chattering effect.

The Ohio Brass Company's insulators, sister-hooks, rods, and Detroit clamps used on the first construction will be used on the extension. There was a question as to whether the use of the porcelain insulators should be continued, but as there has been no difficulty from the breakage of these insulators, and as the composite trolley insulating materials deteriorate in time, Mr. Mather decided to make no change in the type of insulators, although, at the maximum, the voltage will be 600, direct-current.

In the operation of work trains on steam railroads, the speaker's company has found the same difficulty as described by the author.

FIG. 1.—STANDARD WOODEN POLE CONSTRUCTION ON DOUBLE-TRACK ROAD.

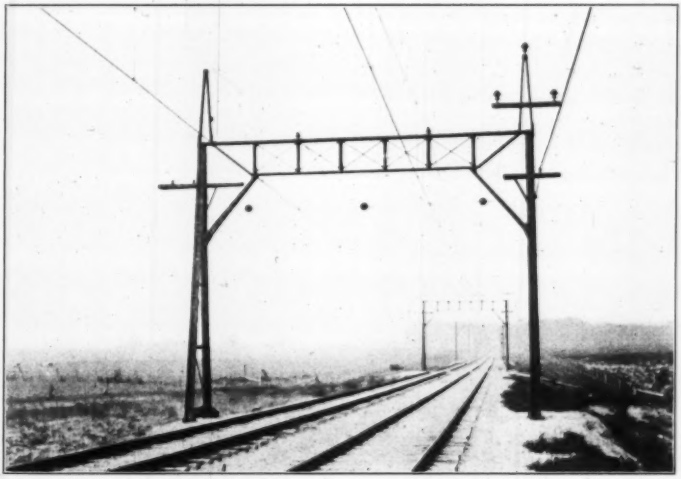


FIG. 2.—CATENARY BRIDGE CONSTRUCTION.

Frequently, only from 3 to 5 hours' work a day can be obtained from a work train with the linemen assigned to it. The charges for construction trains run from $25 to $50 per day, and the payroll of the construction force may easily be as much more. Experience shows that as much work as possible should be done independently of the train. It will be necessary, of course, to deliver bridges, or poles, and to string out the wires from trains during the day time. Where traffic is heavy on a road, it would perhaps be economical to set the hangers at night, and better and more economical results can be obtained, after the wires are strung, by pulling them up with ropes and blocks, with a team or by hand. Mr. Archbold.

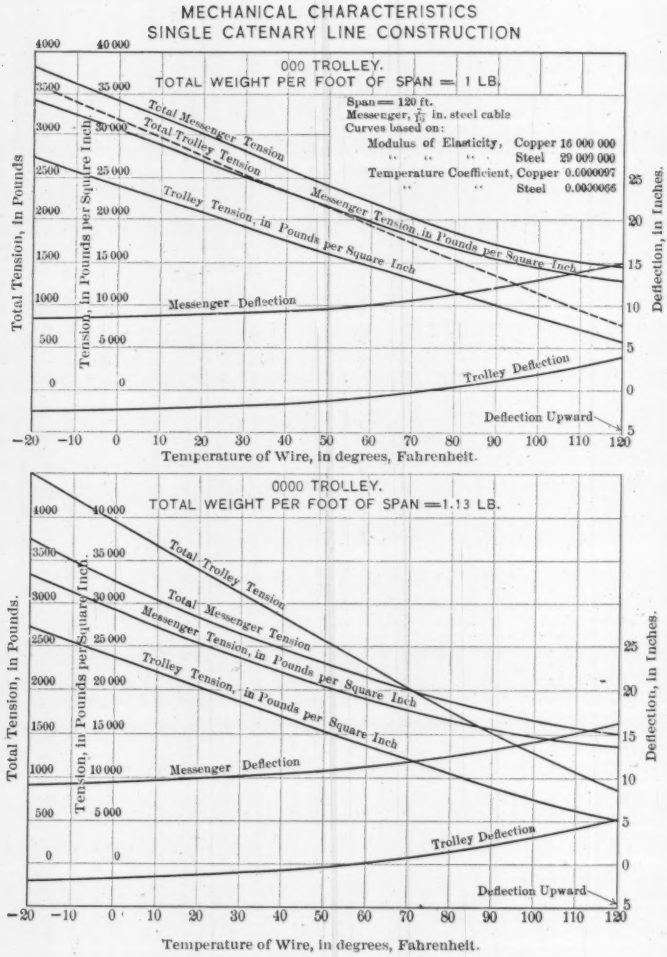
The use of a dynamometer in stringing wire has not seemed practicable, in the speaker's experience, and the best results have been obtained by sighting the wires and using a sag table with proper corrections for temperature changes. The large difference in initial strains in pulling the messenger cable, mentioned by the author, are not so important in the work on the bridges with 300-ft. spans, as there are, of course, fewer points of support to make friction on the wire, and the bridges are more stable than bracketed poles. In the work mentioned, use was made of pulleys, which were attached to the top chords of the bridges, and over which the messenger cables could be run. Even with this plan, there would be some difference in initial strains, but, of course, it would be reduced to a minimum; and, to permit the spans to equalize, the messenger wire should not be tied in until the expiration of a day, or, preferably, two or three days, after it is strung.

THEODORE VARNEY, ESQ. (by letter).—Referring to Mr. Lyford's statements regarding the rapidity with which the construction work was carried out on the Denver and Interurban Railroad, his final rough estimate—$3 500 to $5 000 per mile of single-track construction—appears to be high. This, however, as he says, is probably due largely to interruptions and other contingencies affecting the labor item. It would be interesting to know what the author's estimate would be under the same conditions, providing no regular service had to be maintained during construction, as, for instance, on a new road. Mr. Varney.

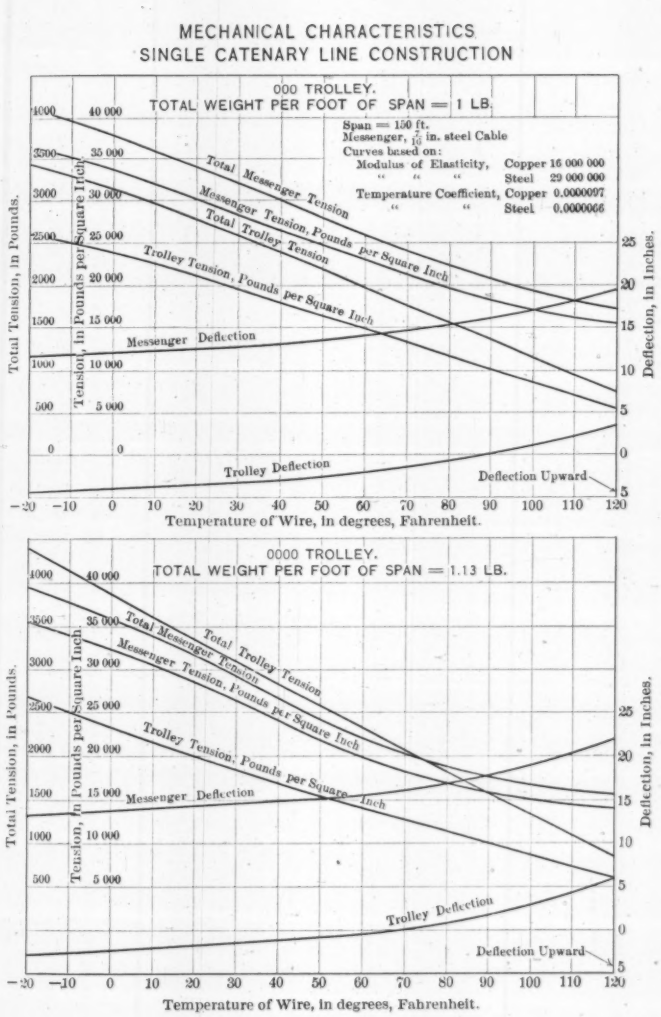
Referring to the question of sag in the messenger cable and trolley wire, the author is undoubtedly correct in his idea of having the trolley wire and messenger cable taut at all temperatures, but it would seem that 2 000 lb. at 100° is tighter than necessary. The diagrams, Figs. 7 to 10, indicate conditions which appear to be entirely practicable. In these curves the tensions in the messenger cable correspond to the load produced by trolley and hangers. In Europe, where automatic tension devices are used, it may be noted that a tension of about 1 100 lb. is maintained on a wire a little less than 000 in size.

It is believed that the pole spacings are rather closer than are

Mr. Varney.



FIGS. 7 AND 8.


MECHANICAL CHARACTERISTICS
SINGLE CATENARY LINE CONSTRUCTION
000 TROLLEY.
TOTAL WEIGHT PER FOOT OF SPAN = 1 LB.
Span = 150 ft.
Messenger, 7/16 in. steel Cable
Curves based on:
Modulus of Elasticity, Copper 16 000 000
" " " Steel 29 000 000
Temperature Coefficient, Copper 0.0000097
" " " Steel 0.0000066
Total Messenger Tension
Messenger Tension, Pounds per Square Inch
Total Trolley Tension
Trolley Tension, Pounds per Square Inch
Messenger Deflection
Trolley Deflection
Deflection Upward
Total Tension, in Pounds.
Tension, in Pounds per Square Inch
Deflection, in Inches.
Temperature of Wire, in degrees, Fahrenheit.
0000 TROLLEY.
TOTAL WEIGHT PER FOOT OF SPAN = 1.13 LB.
Total Messenger Tension
Total Trolley Tension
Messenger Tension, Pounds per Square Inch
Trolley Tension, Pounds per Square Inch
Messenger Deflection
Trolley Deflection
Deflection Upward
Total Tension, in Pounds.
Tension, in Pounds per Square Inch
Deflection, in Inches.
Temperature of Wire, in degrees, Fahrenheit.

FIGS. 9 AND 10.

Mr. Varney. actually required to keep the wire on the pantagraph contact. In the case of a new road, it is undoubtedly best to limit the "stagger" at first until the roadbed has settled, but afterward more deviation than that given in Table 1 is believed to be safe, and will result in longer life to the shoes. It would be interesting to know the length of life of a pantagraph shoe on the Denver and Interurban Railroad. Deviations of at least 7 or 8 in. on each side of the center should be safe for a shoe 4 ft. long on the flat portion.

The question of grounding the bracket arms is one which is deserving of careful consideration. In cases of roads with two or more tracks; where the lines may be broken into comparatively short sections; where the traffic may be diverted to other tracks, while one is tied up for repairs; and, especially, where the necessity for great stability and long spans demands steel supporting structures, a grounded support for the insulator is not objectionable. In these cases, however, automatic devices should be used in order to isolate the grounded section and not tie up the entire system when an insulator breaks. The case is different, however, for a single-track road without automatic sectionalizing devices and with little attendance. Broken insulators are now being replaced on some roads, with 6 600 volts on the line.

It is believed that it would pay to investigate methods of impregnating wood poles in order to make them weather-proof and also fairly good insulators. In every pole 20 ft. of good insulation is being wasted, and this, in case of a broken insulator, should suffice to keep the road operating until the insulator can be replaced.

Mr. Cole. GEORGE N. COLE, ASSOC. AM. SOC. C. E. (by letter).—It is very evident from this paper that one of the main objects in the care used in the erection of trolley lines is to obtain a perfectly level trolley, eliminating sag and swaying.

By eliminating sag a smooth-running pantagraph at high speeds is obtained, and, to eliminate this sag, frequent trolley hangers are necessary. Reference has been made to the fact that at certain speeds a considerable vibration is set up in the pantagraph which causes it to hammer the wire with considerable force, and Mr. Harte mentions a trolley wire which was badly bent at its support from this very cause.

It is evident that this vibration is induced when the rate of passing the trolley hangers is the same as the rate of vibration of the pantagraph and its springs, or some multiple or harmonic of it.

Since, from its present construction, the pantagraph has inevitably a rate of vibration, it occurs to the writer that vibration of the pantagraph would never be started if the trolley hangers, from the messenger wire to the trolley wire, were placed so that no regular rate of passing them would ever occur.

This can readily be accomplished by spacing these trolley hangers

at such irregular intervals that they will fail to pass the pantagraph in a rhythmic manner or set up a beat in it. Mr. Cole.

Care should be taken that this variation in spacing is not made a fixed or regular variation, or a higher vibration might be set up in what one might call an overtone, and give rise to an objectionable hum, or worse.

W. S. MURRAY, ESQ.* (by letter).—This paper has naturally brought to the writer's mind the allied features common to the New Haven electrification. It is, of course, to be noted that there is a wide dissimilarity between the form of construction adopted on the New Haven system and that described by the author. Both, however, are tied to a common factor, namely, the frequency, phase, and voltage, and although, even here, certain detailed electrical operating conditions are not entirely similar, the closeness of the relation may make valuable the citation of some experiences on the New Haven system. Mr. Murray.

The writer approves heartily of the methods relative to construction in the field, so well described in this paper. Doubtless Mr. Lyford has found out that the work train is the "heart-wringer" of the operating department. It requires the highest order of intelligence to control its movements, and the labor in connection with it is paramount. It is most important that the work-train organization be of a character to insure the maximum possible number of work-minutes during the day and the least number of minutes of interference with the revenue train schedule; the roster of each man's time must be laid out by previous schedule, and not arranged on an *ex-tempo* basis in the field. In reviewing the time rates Mr. Lyford has mentioned, concerning the erection of poles and brackets, it would seem that just such a perfection of work-train schedule had been secured. The cost of labor can jump in factors of two, three and, indeed, as high as four times the minimum if every care is not exercised in the outlay of the time and the location of the work-train service. Again, emphasis should be placed on the necessity of the contractor remembering that the train despatcher can be either his best friend or his worst enemy, and, if the latter, he can easily be forgiven, as there is nothing that makes such havoc in a railroad schedule as a work train.

Mr. Lyford's summation of the several railroad companies who have trains under electrical operation or have framed definite plans for their operation by electricity is of great interest, and the fact that, out of the number mentioned, 50% have chosen single-phase electrification proves the directional tendency of the new art. Many have already grown gray-haired over the period in which car or train propulsion has been obtained by the direct current, and, indeed, all may be proud of the splendid achievement and the degree of perfection secured in this form of electric propulsion. As a matter of fact, its very limita-

* Electrical Engineer, New York, New Haven and Hartford Railroad.

Mr. Murray. tions have been the cause of its perfection, and in the new art may be seen this high notch of direct-current perfection, the starting point for greater attainments to be secured in the application of single-phase traction.

There is no little pleasure in the realization of a prophecy the writer felt so sure would be fulfilled, namely, the approval by the Public Service Commission of the high-tension wires erected on the right of way of the New York Central Company within the limits of the City of New York. In the recent decision of Commissioner Eustis may be found a just and careful reasoning. The greatest argument against the use of high-tension wires within city limits is prejudice. Analyze prejudice and invariably the fibers of its structure disintegrate. Officials who are above prejudice, and judge a situation absolutely on its merits, must be constrained to decisions in which the public and the railroad company's interests are fairly equated. It is no strain of conscience or discernment to realize that frequently the railroad's interest is the public's interest.

The writer fears that he is deviating slightly from a discussion of this paper, and yet Mr. Lyford says:

"The principal merit in the single-phase system lies in the ability to operate at high voltage with a single overhead conductor, and, therefore, to transmit power long distances with a minimum number of sub-stations and a minimum quantity of copper. These arguments apply particularly to trunk-line operations, and this system, therefore, appeals especially to the managers and engineers of large railroads."

Concerning the use of phono-electric trolley wire *versus* hard-drawn copper, the writer cannot quite agree with Mr. Lyford in the reasoning by which he arrives at the unimportance of its low conductivity, in virtue of the higher resistance of the steel rail to the path of the current; the writer would rather be led to the necessity of keeping out any further extra resistance. It is quite true that, by the introduction of this higher rail resistance, the percentage of drop in the overhead wire to the total circuit drop is less, but it is the total and not this percentage which is of the greater importance. However, notwithstanding this reasoning to the contrary, between the two wires, the writer is in favor of the choice made by Mr. Lyford in the use of the phono as a contact wire (conductivity being supplied by other means), for, as such, experience indicates that, though always higher in cost per pound, it is not only cheaper than copper, as its life is more than twice as long, but its reliability and resistance to fracture is also one of its marked advantages.

To return to the form of construction described by the author, its successful operation is dependent entirely on the speeds to be made. If such speeds as have obtained on the New Haven tracks are to be negotiated on Mr. Lyford's line, the writer would prefer the form

of suspension the New Haven road has recently adopted. It is unquestionably more expensive than the type described by Mr. Lyford, but it fulfills one of the requirements laid down by him under "sufficiency," with which the writer is in full accord, namely: Mr. Murray.

"High-voltage catenary work cannot receive the close daily inspection of the track-walker, and, because this is so, there is the greatest necessity for thoroughness and permanence in the construction."

There is a perfect analogy between a catenary form of overhead trolley construction and a regular highway suspension bridge. If a highway bridge of the suspension type is to be built, the engineer first asks what is to be its traffic density; how many car tracks are to be laid on it; how many wagons are to be permitted to pass; what load is to be concentrated at any point; in short, what is to be the commercial duty of the bridge? Having obtained this information, he then designs the cables and general members of the bridge, and finally the floor, the latter usually being cheap and quickly and easily replaced. The electrical engineer likewise wants to know something about the traffic on his bridge. He will certainly want to know what the current density is to be, and, with this information, he must design sufficiently strong cables to hold up his copper conductors and take care of the current traffic; and, finally, why should he not design the floor of his bridge, namely, the cheap easily replaceable iron wire? Can it not be agreed that electrical engineers have been making the mistake of running on the members instead of the floors of their bridges, and thus slowly, but surely, decreasing the (current) traffic capacity of their structures? If the engineers of the highway suspension bridges were to run on the members of their structures, the bridge would soon fail; thus, by the use of the auxiliary wire, one approaches, if he does not reach, a state of the electrical art which has for its guarantor many years of mechanical experience.

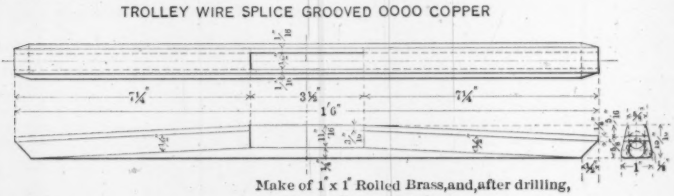
The relative life of phono *versus* steel wire is one of the most absorbingly interesting details, and later the writer hopes to be able to offer some statistics which may be valuable to those engaged in electrification. There is no more important link in the distributing system than the contact wire. Next to the traffic rails, it is the most abused piece of metal exposed, and it deserves a high order of consideration. The writer agrees most heartily and earnestly with the author in his statement that hard spots in the catenary construction should be eliminated. Indeed, they make inoperative a high-speed line, and, considering the hard spots individually, the writer would name, in the order of their degree of menace to high-speed operation, deflectors, section breaks, and hangers. Engineers have eliminated the hard spots due to the hanger, and are studying how to eliminate the others. It is a happy provision that the two latter are comparatively few as compared to the first named. The writer has every reason to believe that

Mr. Murray. the same success obtained in cushioning the hard spots, due to hangers, can be secured in the proper design of steady strains, deflectors and section breaks. In any one of these classes of construction an adherence to the general form of line construction should be followed.

It is pleasing to note Mr. Lyford's choice of 4 or 5 miles as sectionalizing distances. Actual operation has proved the advantage of this distance, and, although originally sections averaged 1½ miles in length, in some instances, this distance is now increased to the figures above named.

It is interesting to note the figures, mentioned by Mr. Lyford, covering single-phase electrification; the writer is able to vouch for their conservativeness. The careful record of expenditures made, to date, upon a four-track electrification has presented a distribution of costs most interesting to study. The entirely successful experience undergone in the past year with the cross-catenary form of construction in the East Portchester yard, where as many as ten tracks are spanned, strengthens the writer's previous belief that in the future this form of construction will have excellent application to roads having four or more tracks, upon which occasion he believes the cost of electrification per single track will be considerably below the figures named by Mr. Lyford.

Mr. Coombs. R. D. Coombs, M. Am. Soc. C. E.—In connection with the detail of the trolley splicing sleeve shown by Mr. Lyford, the following tests recently made during the installation of the experimental line of the Pennsylvania Terminal and Tunnel Railroad on Long Island, may be of interest.



Make of 1" x 1" Rolled Brass, and after drilling, machine to dimensions shown

Fig. 11.

On account of the small vertical distance between the secondary messenger and the trolley wire, a compact splice was required, and four samples were made and tested.

The first sample was identical with that shown in Fig. 3; the second was like the first, except that the bottom surface was rounded; the third and fourth were as shown in Fig. 11. It was the intention to solder short lengths of 0000 grooved trolley wire in each sleeve and then test them to destruction in a tension machine. On attempting to solder the first and second samples, the material cracked along the

middle of the bottom surface for a distance of about 6 in. from the end. The third and fourth samples were soldered without difficulty, using 0000 hard-drawn grooved copper wire for the former and 0000 medium-steel grooved wire for the latter. Mr. Coombs.

No. 1.—Cracked in soldering.

No. 2.—Cracked in soldering.

No. 3.—0000 copper, 7 630 lb. ultimate strength, 46 000 lb. per sq. in.

No. 4.—0000 steel, 11 630 lb. ultimate strength, 72 000 lb. per sq. in

In both instances failure occurred in the trolley wire outside of the splice. Two additional pieces of the wires used were tested and gave substantially the same results, showing that no injury was done to the wire in soldering.

By planing off the upper corners, as shown in Fig. 11, the speaker attempted to lessen the weight of the splice and obtain if possible some slight elasticity at the ends of the sleeve. It would appear, from these tests, that the removal of this unnecessary material tended to prevent unequal contraction and cracking.

As stated by Mr. Lyford, intelligence and experience are needed in the design of overhead material, and the cost of time spent in developing workmanlike designs will be saved over and over again in the field. Not only the simplicity of each aerial erecting operation, but also the number of operations, must be considered. Assuming that a given catenary detail is mechanically able to perform its function, that it will not interfere with the desired elasticity of the line, and that it induces a minimum of aerial work, it will still be undesirable unless free from wear and corrosion.

This question of maintenance deserves more careful consideration. On lines of little traffic repairs may be possible at a reasonable cost, but it is not believed that the average operating department would view with composure the need for much work-train service on a busy line.

The life of galvanized material exposed to the elements or to locomotive gases, or to both, is a subject upon which there is great difference of opinion among engineers. If it is a fact that galvanized material cannot withstand the atmosphere of the coke regions for even a short period, there would appear to be urgent need of tests before galvanizing alone, or in conjunction with a carbon deposit from the locomotive exhaust, is accepted as sufficient protection. Further, the value of the usual tests of galvanized material is open to some suspicion, if the application of a minute quantity of grease will enable a rejected sample to pass the test.

The speaker is of the opinion that longer spans and fewer supports are desirable. As stated in a previous paper,* the multiplication of posts near the tracks is objectionable in appearance, increases the risk

* *Transactions*, Am. Soc. C. E., Vol. LX, p. 505.

Mr. Coombs. from derailments, interferes with the view of signals, and is subject to considerable discussion as a measure of economy.

Theoretically, as the cost of the material between the supports is relatively low, much longer spans would be economical. The principal objection to long spans is founded upon the possibility of lateral displacement by wind. This is undoubtedly possible, but, in the speaker's opinion, it has been given undue importance in various designs; in fact, he believes that even the 300-ft. spans recently installed on two roads in the United States might have been increased with advantage.

Mr. Lyford. OLIVER S. LYFORD, JR., M. AM. SOC. C. E. (by letter).—The writer wishes to express his appreciation of the valuable contributions made in the discussion.

Referring to Mr. Harte's remarks, the writer regrets the oversight in not mentioning the notable pioneer work of Colonel Heft in the third-rail installation between Hartford and New Britain.

The methods of overhead construction described by Mr. Harte are significant as indicating how the construction problem must be studied in advance of the selection of methods.

Answering the inquiry regarding soldering sleeves: There was no sleeve on the market which was as strong as the wire and would not weaken the wire at the point of entry. The objection to an eye turned in the trolley wire is similar; bending the wire on a short radius materially reduces its strength. The sleeve described was the best expedient suggested in the emergency. Mr. Coombs relates experience with trolley sleeves, of the pattern described in the paper, which cracked when being soldered. There were no such experiences reported on the Denver and Interurban work, and this trouble with the untapered sleeves was probably due to flaws in the drawn bar from which the sleeves were made. This is not an infrequent occurrence with drawn material, selected at random, and subjected to transverse internal strains.

The rigid hanger construction is probably limited to service where the speeds are not more than 60 miles per hour, and to construction with close pole spacing, that is, not greater than 120 ft. If the trolley wire is hung properly and does not stretch badly, pantagraphs used in connection with such construction will have a life of from 12 000 to 20 000 miles, and the wear of the wire is slight. The following letter from Mr. R. C. Thurston, Electrical Supervisor of the Rochester Division of the Erie Railroad, is quoted:

"ERIE RAILROAD COMPANY.

"AVON, Sept. 21, 1908.

"MR. O. S. LYFORD, JR., New York.

"MY DEAR MR. LYFORD:

"Replying to your letter of Sept. 16th, will say that about Aug. 16th I measured the trolley wire on both ends of the line with the following result:

"New wire measures 0.438 in. from top to bottom, or wearing surface; on the Rochester end the wire at the date mentioned above measured 0.434 in., or an approximate wear of 0.004 in. at this point since going into operation, and represents the wear of 7 440 cars. On the Mt. Morris end the wire now measures 0.429 in. or a wear of 0.009 in., and represents the wear of 10 230 cars. You will probably ask if the wear is greater in low spots (as going under bridges) than at standard (22 ft.) height. I could not detect any difference. I might add that in spots the dimensions are less, owing to the fact that in these cases the trolley clamps are not square with the wire, which made a 'kink' and caused the pantagraph to hit harder than usual. Mr. Lyford.

"Regarding the wear of the pantagraph shoes, will say that about 15 000 miles is the life of them; they are made of 3/32-in. steel.

"Yours truly,

"R. C. THURSTON."

The line referred to is approximately 34 miles along. The number of cars passing one point daily on the Rochester end is 16, and on the Mt. Morris end 22. These cars are geared for 55 miles per hour. The trolley wire is 000 hard-drawn copper; possible wear, before striking hanger clamps, 19 in.; life of wire subject to normal wear, on this basis, 20 to 30 years. The wear at certain points is no doubt greater than this, and renewals in spots will be necessary in much shorter time. Increase in the service will naturally decrease the life of the wire proportionally. It is believed that the harder and stronger material used on the Denver and Interurban will make a much better showing than the hard-drawn copper.

The smoke troubles on the Erie have been very slight. The same line insulator is used as on the Denver and Interurban, and the design seems to be suitable to resist the deleterious action of a moderate amount of steam locomotive gases.

In answer to Mr. Harte's question, the cross-catenary span construction was used, instead of simple suspension, in order that insulators and pins of the same type as on bracket construction could be used. The pull-offs are also provided without special work.

Mr. Varney's comment, that the figures quoted by the writer for cost per mile of catenary construction appear to be high, is probably due to the fact that he views these matters from the standpoint of the contractor rather than that of the railroad. In such work there are many items of cost which the railroad has to take into account, but which the contractor for the catenary work does not share; that is, greater or less changes in road construction are necessary, connections to the power-station have to be made, etc. The limits given are believed to be as close as practicable for a general case such as described under the heading of "Cost."

Mr. Varney's sag tables, as the writer understands them, give the characteristics of a line after it is erected, but give no indication of how a line could be erected to match the curves. The curves given in

Mr. Lyford. the paper are in reality a set of instructions for erecting the messenger and trolley wire, and do not give the strains expected after the line is completed.

Comment is made that a minimum strain of 2 000 lb. appears to be high, but such information as has reached the writer from other roads indicates that where the trolley wire, supported with rigid hangers, has been strained with low tension, it has usually been necessary to pull out the slack before the pantagraph would ride smoothly on the wire.

Concerning Mr. Murray's comments regarding the importance of low conductivity, some additional figures will perhaps clarify the statements made in the paper.

Under the probable condition of peak loads on the Denver and Interurban, the calculated voltage drop in the trolley and tracks with 000 hard-drawn copper wire is 690 volts, and with phono-electric wire 960 volts. The delivered voltage being 11 000, the drop in trolley and tracts, expressed in terms of the delivered voltage, is increased from 6.27% to 8.73% by the use of the alloyed metal.

In this high-voltage system the drops experienced in an overhead structure, the elements of which are selected for mechanical sufficiency, are much less than those commonly experienced in low-voltage, direct-current systems. This means better speed characteristics on the sections at a distance from the power or sub-station.

One other advantage anticipated from the use of a metal harder and stronger than copper for the contact wire is that it will not stretch as pure copper does. It seems probable that copper wire will continue to stretch and the slack must be pulled out periodically.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1097

THE HYDRO-ELECTRIC DEVELOPMENT AND TRANSMISSION LINES OF THE CANADIAN NIAGARA POWER COMPANY.*

By A. H. Van Cleve, M. Am. Soc. C. E.

With Discussion by Messrs. John C. Parker, William J. Boucher, and A. H. Van Cleve.

History and General Scope of the Development.

As soon as the hydro-electric development of The Niagara Falls Power Company, at Niagara Falls, N. Y., was fairly under construction, the attention of capitalists was attracted to the water-power possibilities of the Canadian side of the Niagara River. The conditions for development there differed materially from those on the American side, owing to the fact that all the land adjoining the Horseshoe, or Canadian, Falls was and is owned by the Province of Ontario, being reserved as a public park and administered by a Park Commission. As is evident by an inspection of Fig. 1, the Queen Victoria Niagara Falls Park embraced all the most desirable sites for power-plants, and, as the entire lower bank of the gorge from the Falls to a point near Lake Ontario was included in the Park Reserve, it was evident that a hydro-electric development could take place only by arrangement with the Park Commissioners.

* Presented at the meeting of October 21st, 1908.

Accordingly, on April 7th, 1892, an agreement was entered into between Messrs. Albert D. Shaw, Francis Lynde Stetson, and William B. Rankine (representing a company thereafter to be incorporated), and the Commissioners for the Queen Victoria Niagara Falls Park, granting exclusive rights for taking and using the waters of the Niagara River within the limits of the Park, excepting as certain minor grants had previously been made. The agreement provided for the payment of certain rentals, which increased from year to year and were independent of the amount of power developed.

In view of the present state of the art, it is interesting to note that the company was granted the right to generate and transmit pneumatic power as well as electricity, thus showing that, in the minds of the incorporators, at least, the success of the generation and transmission of electric power was not so assured as to dispense with a provision for other forms of power.

The agreement further provided that, on or before November 1st, 1898, the company should complete water connections for the development of 25 000 h. p., and should at that date have ready for use and transmission 10 000 h. p. The agreement with the Park Commissioners was ratified by the Legislative Assembly of the Province of Ontario on April 14th, 1892. The company formed to carry on the power development was known as the Canadian Niagara Power Company.

By reference to Fig. 1 it will be seen that there was a body of water separated from the rapids above the Falls by Cedar Island. In the original plans it was proposed to deepen this natural channel and to connect it with the river by a wide mouth at the upper end of Cedar Island. Such canal was to supply water to three successive developments of 50 000 h. p. each, two tunnels being provided for discharging the water north of the Horseshoe Falls. There were numerous engineering objections to the plan proposed, and it is, indeed, doubtful whether a plant thus located could have been operated successfully during adverse ice conditions. In locating and designing a power-plant in a beautiful park, æsthetic, as well as engineering. conditions must be conformed to, and such conditions affected not only the site originally selected but also that finally adopted, the question of harmony with the surroundings being ever present in the minds of the designers.

No construction took place at the point described. Many of the

FIG. 1.—PUTTING PUDDLE IN COFFER-DAM.

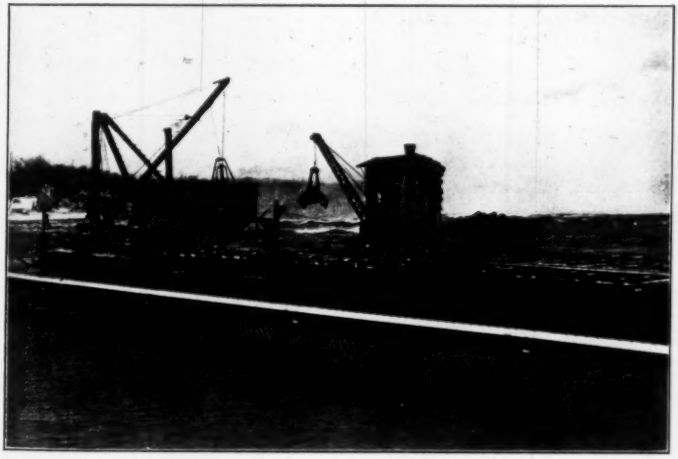


FIG. 2.—METHOD OF REMOVING COFFER-DAM.

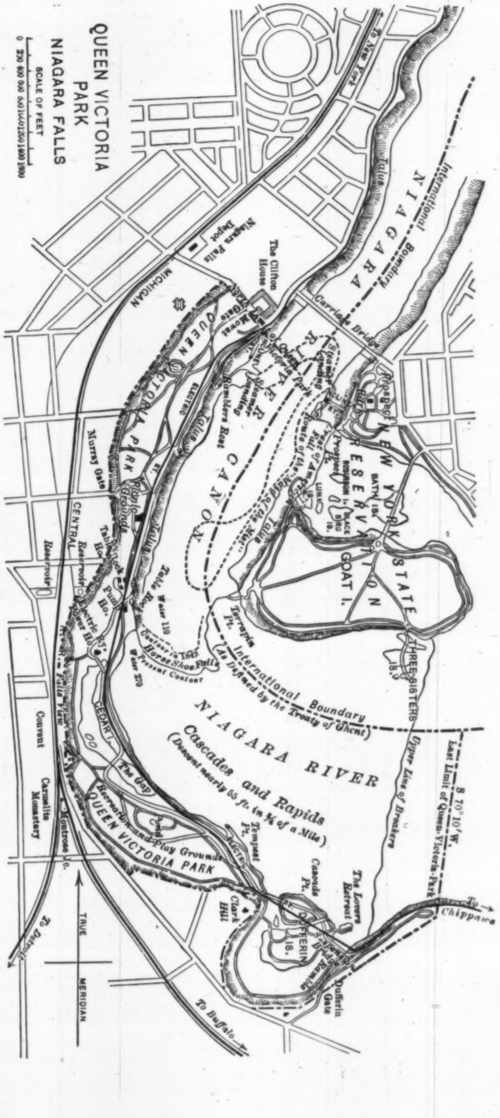

QUEEN VICTORIA
PARK
NIAGARA FALLS
SCALE OF FEET
To New York
NIAGARA
International Boundary
Talus
Niagara Falls Depot
The Clifton House
MICHIGAN
Carriage Bridge
North Gate
Mowat Gate
QUEEN VICTORIA PARK
ELECTRIC
Steamer Landing
Ramblers Rest
CAÑON
Prospect Park
Prospect Pt.
NEW YORK STATE RESERVATION
BATH IS.
LUNA
BLACK BIRD IS.
GOAT I.
Murray Gate
Picnic Grounds
CENTRAL
Reservoir
Table Rock
Pump Ho.
Electric Ry. Power Ho.
Table Water 110
Horse Shoe Falls
Present Contour
Water 270
Terrapin Pt.
THREE SISTERS IS.
International Boundary (As Defined by the Treaty of Ghent)
NIAGARA RIVER
Cascades and Rapids
(Descent nearly 55 ft. in ¾ of a Mile)
Upper Line of Breakers
S 70° 10′ W.
East Limit of Queen-Victoria-Park
CEDAR I.
The Gap
Convent
Carmelite Monastery
Montrose Jc.
Recreation and Play Grounds
QUEEN VICTORIA PARK
Tempest Pt.
Cascade Pt.
The Lovers Retreat
Clark Hill
DUFFERIN IS.
Dufferin Gate
To Chippawa
To Detroit
TRUE MERIDIAN
To Buffalo

FIG. 1.

capitalists were interested both in the Canadian Niagara Power Company and in The Niagara Falls Power Company, and, during the years from 1890 to 1900, the latter company was working out many novel problems in hydro-electric development, and it was desired that the Canadian company should take advantage of all the experience to be gained in the design and operation of the American plant.

The period referred to in the original grant thus elapsed with only a nominal amount of work being done, and, on July 15th, 1899, a supplemental agreement was entered into between the Canadian Niagara Power Company and the Park Commissioners which rescinded that clause of the former agreement which made the company's rights for the use of water a practically exclusive one, made the rental partially dependent upon the amount of power generated, and extended the time for the completion of the first development to July 1st, 1903. The time at which the company was to have ready for use, supply, and transmission 20 000 h. p. was afterward extended by agreements and legislative enactments to January 1st, 1905, and the requirements were complied with at that date.

The agreement of July 15th, 1899, provided in detail that not only the designs of the works of the company but also the manner of their construction should be subject to the approval of the Park Commissioners, and the document was accompanied by the map shown on Fig. 2, indicating the point at which the first development was to take place, as well as the general character of its design.

It will be noted that the works have been moved up the river from the site originally selected. The length of the discharge tunnel was thus increased, but the form and location of the inlet canal were better suited to meet ice conditions. But small saving could have been effected by utilizing the natural watercourse, as it was shallow. It is evident that the ideal location for the power-house was on the shore of the river opposite its present position, but objections were made to such a site on the ground that a building at that point would interfere with the view of the rapids.

The plan shown on Fig. 2 contemplates an ultimate development of 100 000 e. h. p. by twenty units of 5 000 e. h. p. each, with two spare machines. This plan was one of the general drawings accompanying the agreement of July 15th, 1899, previously referred to. Thus far in the course of the design, units of a capacity greater than 5 000

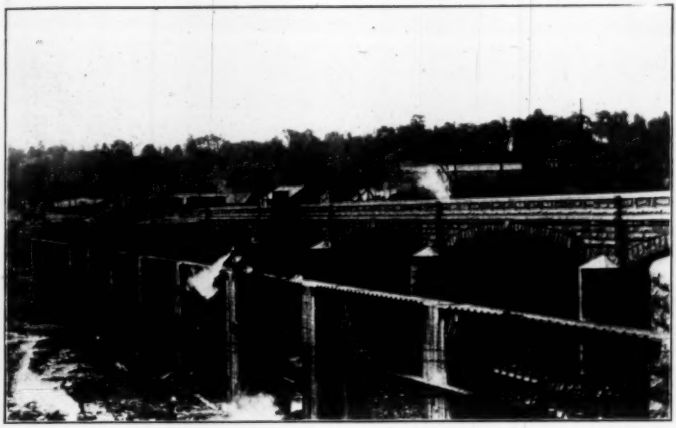


FIG. 1.—OUTER ICE RACK.

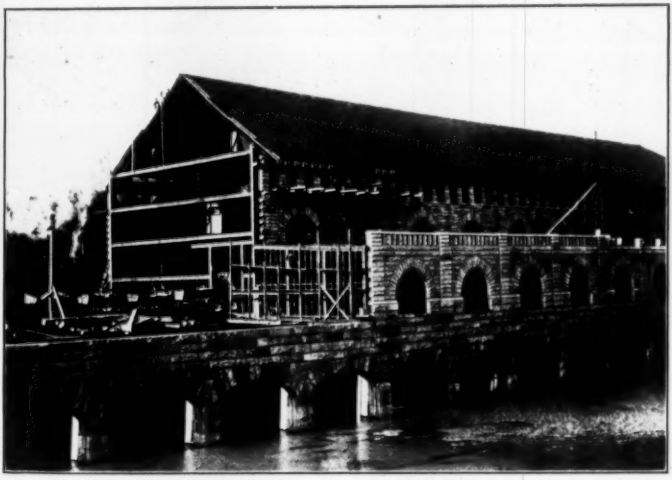


FIG. 2.—SUBMERGED ARCHES UNDER FOREBAY WALL.

e. h. p. had not been contemplated, but the state of the art had advanced sufficiently so that in 1901 inquiries submitted to manufacturers of both hydraulic and electrical machinery elicited favorable replies as to their ability to design and furnish machinery for units of 10 000

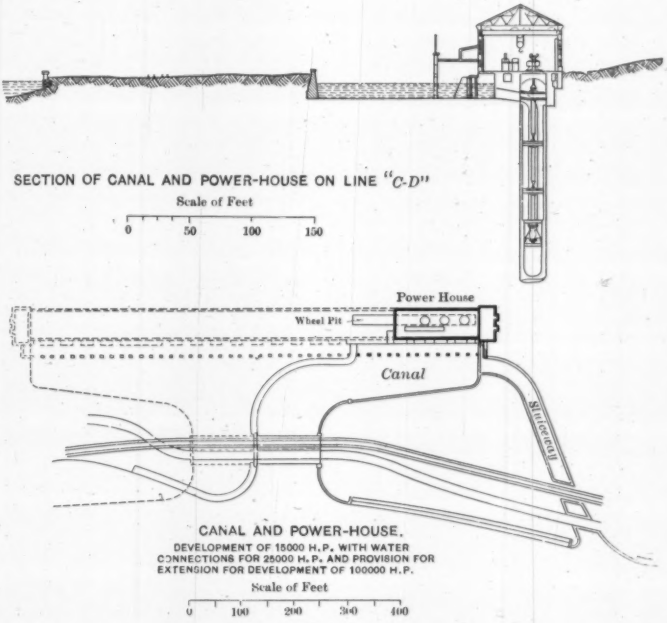


FIG. 2.

e. h. p. The larger unit was adopted for the final design, the following being among its advantages:

(*a*)—Somewhat lower cost of hydraulic machinery per horse-power developed;

(*b*)—Materially lower cost of electrical machinery per electric horse-power developed;

(*c*)—Decreased length of canal, wheel-pit, and power-house, thus effecting a large economy in the cost of excavation and masonry;

(*d*)—Opportunity for increased development within the area in the Park assigned to the Canadian Niagara Power Company;

(*e*)—Convenience and economy of operation due to the reduction in number of units, it being remembered that the bus-bars of the plant under consideration were to be connected with those in the power-houses of The Niagara Falls Power Company, where 5 000-e. h. p. units were available to subdivide the load.

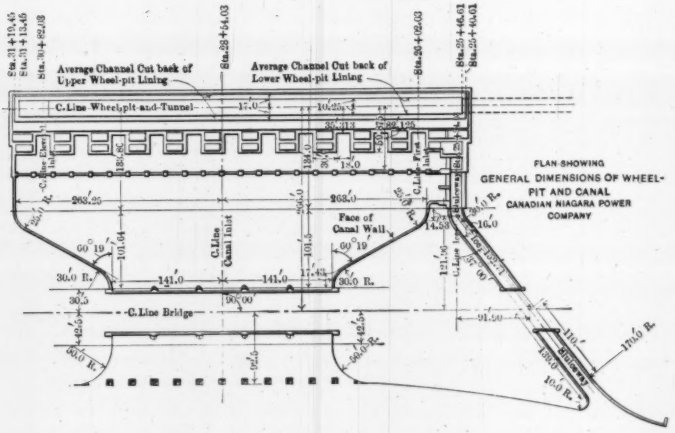


FIG. 3.

The increase in the size of the units, of course, resulted in changes in the entire design of the plant, and on Fig. 3 is shown the general arrangement finally adopted.

At the time of the agreement of July 15th, 1899, it was the intention to provide water connections for 25 000 h. p. only, and to excavate a wheel-pit for only five units of 5 000 e. h. p. Before any contracts were let, it was decided to make water connections for 50 000 h. p. and to excavate a wheel-pit 250 ft. long, two units of 10 000 e. h. p. to be installed. Finally, on February 2d, 1903, a contract was let for the completion of the canal and wheel-pit to their full capacity. The plant, as now constructed, consists of a canal, wheel-pit, and tunnel having a designed capacity of 100 000 e. h. p., an installation of five

FIG. 1.—SOUTH END OF WHEEL-PIT UNDER CONSTRUCTION.

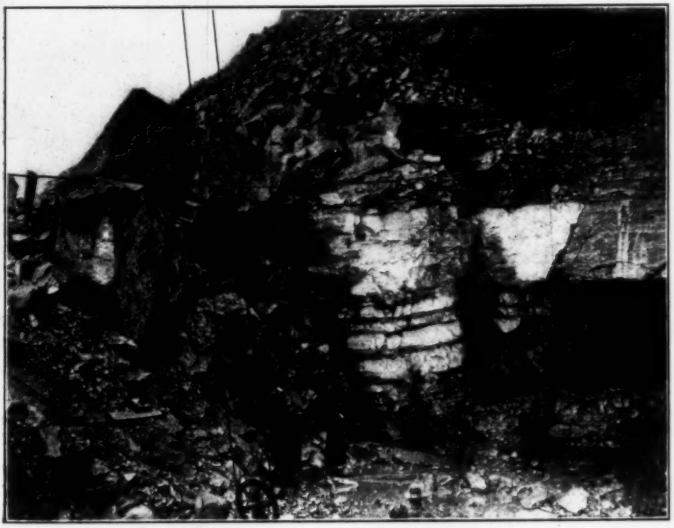


FIG. 2.—TUNNEL PORTAL, UNDER CONSTRUCTION.

units, each having a nominal capacity of 10 000 e. h. p., and a power-house sufficiently large to enclose them.

Having given the foregoing introductory remarks in regard to the history and general scope of the development, the writer will now describe the more important features of the several parts of the plant.

Coffer-Dam and Canal.

In order to obtain a sufficient depth of water at the entrance to the canal, it was evident that a portion of the river bottom would have to be unwatered, that the necessary excavation might proceed. It was a perilous matter to obtain in the rapids the soundings which were requisite for a determination of the limits within which such excavation was necessary, but, after several narrow escapes in the turbulent current leading to the Horseshoe Falls, the necessary soundings were obtained and a coffer-dam was constructed to enclose the desired area, a depth of 15 ft. of water being secured where possible. The coffer-dam consisted of two rows of rock-filled cribs with a puddle space between, additional tightness being secured by double sheeting and a concrete toe on the inside. Fig. 1, Plate XX, shows the coffer-dam at the stage when the puddle was being placed, and, as shown in this photograph, the turbulence of the water gives an idea of the difficulties encountered in its construction.

The removal of the coffer-dam proved almost as difficult a problem as its construction. The progress made by the contractor was so slow that, in view of the necessity of operating the plant, the engineers had to assume control of this work. The method finally adopted is illustrated in Fig. 2, Plate XX. The rock was removed to the water line by hand, the puddle was dredged by an orange-peel bucket attached to a Brown hoist, and the turnbuckles uniting the cribs were blown apart by dynamite. The upper timbers were removed, the cribs were racked by light charges, pulled apart by the heavy traveling derrick shown at the left, and the remaining material was dredged with the extra heavy orange-peel bucket. Soundings determined when the original surface was uncovered. Unusually severe winter weather added materially to the difficulty of the work.

Fig. 3 shows the form and dimensions of the finished canal and its relation to other parts of the plant. The water areas are selected so that, when 100 000 h. p. is being generated, the average

velocity, with the water at low stage, will be 2.7 ft. per sec. at the entrance, 3 ft. per sec. under the bridge, and 2.35 ft. per sec. through the submerged arches separating the forebay from the main canal.

Bridges were necessary to carry a driveway and a double-track electric line across the canal and ice sluiceway. Occupying a prominent position in the Park, it was desirable that the bridges should present a pleasing appearance, and reinforced concrete arches faced with limestone were adopted, there being five spans of 50 ft. each at the canal crossing. No special difficulties were encountered in the construction of this bridge, and, notwithstanding the small ratio of rise to span (1:10), the settlement was negligible.

The position of the plant below the principal cascades of the river makes the ice conditions difficult, as the Niagara River carries large quantities of ice during the greater part of the winter. Normally, the most of it passes close to the northerly side of the river, but when the wind is easterly and northerly large quantities are carried to the Canadian side, and, in its progress down the rapids, is finely broken and, by the turbulence of the water, is carried to a great depth below the surface. Under certain conditions true frazil is abundant, but is far more prevalent on the American than on the Canadian side. The plant is protected against ice in the following manner:

(*a*)—By a rack of 2-in. inclined bars, spaced 12 in. apart, connected with a steel framework carried by the masonry piers at the entrance to the canal, such piers being shown at the bottom of Fig. 1, Plate XXI. This rack extends 4½ ft. below the normal water surface, and was originally intended to ward off only large cakes of ice. For the purpose of keeping out fine ice, steel plates were afterward attached to the rack, and, although only partly successful in accomplishing their purpose, produced an unlooked-for result. The water outside of the rack is in a state of violent disturbance, the waves being about 5 ft. in height. Before the attachment of the plates, the rise and fall of the water surface inside the rack was the same as that outside, but the plates naturally produced a stilling effect and the river surface was alternately higher and lower than that in the canal. This alternation of relative levels had the effect of a constantly recurring series of blows upon the piers to which the rack is attached. Although the several courses of masonry were connected with two 1½-in. rods, these were in some cases broken, and the upper portion of the piers tilted outward.

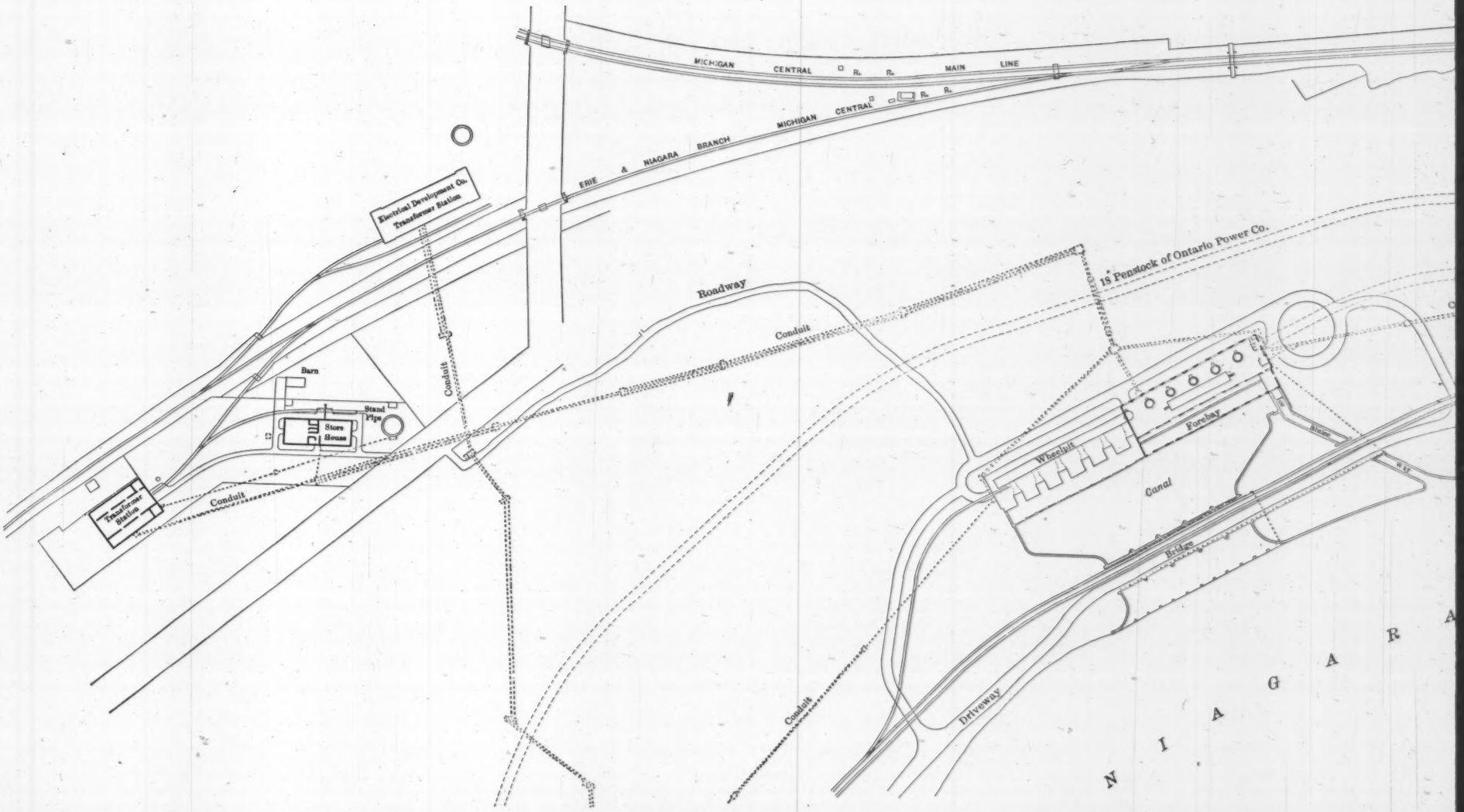
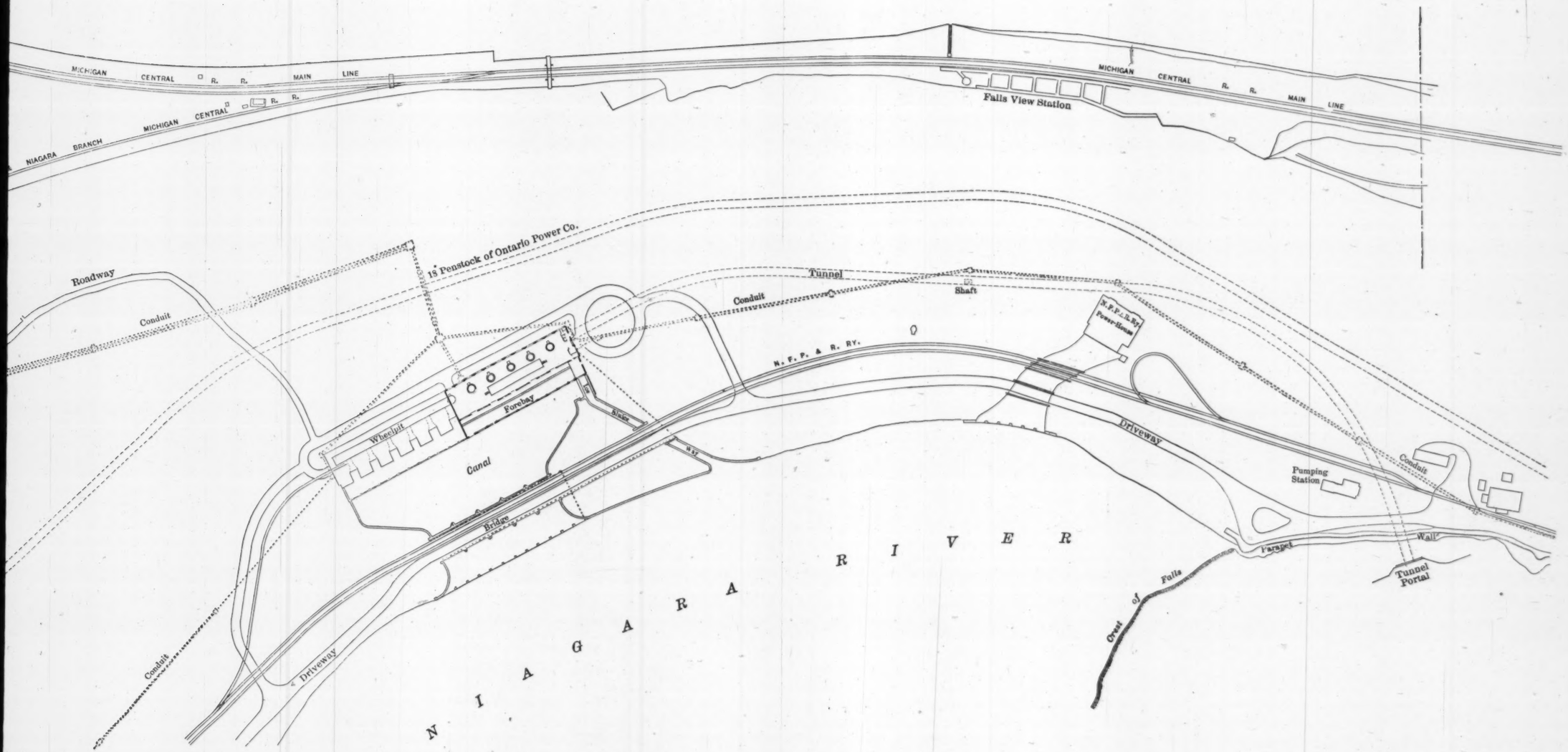

MICHIGAN CENTRAL R. R. MAIN LINE
MICHIGAN CENTRAL R. R.
ERIE & NIAGARA BRANCH
Electrical Development Co. Transformer Station
Roadway
Conduit
Conduit
Conduit
Conduit
Conduit
18' Penstock of Ontario Power Co.
Barn
Stand Pipe
Store House
Transformer Station
Wheelpit
Forebay
Canal
Bridge
Driveway
N I A G A R A

PLATE XXIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXII, No. 1097.
VAN CLEVE ON
THE CANADIAN NIAGARA POWER PLANT.



It has become necessary to strengthen the piers by the addition of two 2-in. rods carried from the top into the ledge rock 2 ft. below the canal bottom. Fig. 1, Plate XXI, clearly shows the rack as originally constructed and the bridge previously referred to. Afterward, a railing and electric light poles were added to the footwalk.

(*b*)—The outer wall of the forebay superstructure rests on a wall of first-class masonry containing a series of arched openings 19 ft. 9 in. wide, the crown of each arch being 2.1 ft. below low water or 4.8 ft. below mean water. Two openings are provided for each unit. The edges of the openings are rounded, and their sides are smooth-pointed. Fig. 2, Plate XXI, a photograph taken near the close of the construction period, shows the character of the masonry arches and their relation to the power-house and forebay. This arrangement of submerged openings effectually prevents the entrance into the forebay of floating ice and such other floating material as may find its way into the canal.

(*c*)—It was evident that some means must be provided for removing from the canal such finely-divided ice as might pass the outer rack, as otherwise it would accumulate in the canal and, by adhesion to the underside of the surface ice, reduce the water area materially. If allowed to accumulate to a depth below the tops of the arches, it would be carried into the forebay. The construction of a shaft connecting with the outlet tunnel would have been expensive, and to have disposed of the ice in this way would have reduced the tunnel area available for discharge water from the turbines and would have introduced serious cross-currents in the tunnel. Fortunately, the rapid descent of the river below the mouth of the canal enabled a discharge channel to be built, as shown on Fig. 3. A difference of level of about 2 ft. is thus obtained between the surface of the water in the sluiceway and that in the canal. The sluiceway has a width of 16 ft. and a depth of water of about 10 ft. It is separated from the canal by masonry weirs, the tops of which are 2.2 ft. below low water. A further separation is effected by steel gates sliding in cast-iron grooves, as shown on Fig. 4. Two openings, each 16 ft. in width, provide for the flow of ice from the canal, while a third gate of similar construction allows the escape of any material which may enter the forebay. The gates are operated by hand-power, although provision is made for the attachment of motors.

(*d*)—A steel rack, composed of 3 by $\frac{3}{8}$-in. bars, $1\frac{3}{4}$ in. apart, making an angle of 60° with the horizontal, extends the entire length of the forebay, thus protecting the entrances to the penstocks. Its construction calls for no remark except the statement that it is in three sections vertically, the middle sections, 3 ft. 4 in. wide, sliding in grooves and adjustable in any desired position. The supporting framework was designed to resist a water pressure of 2 ft., it being considered that a sudden flow of frazil might clog the racks before they could be cleared.

The excavation of the canal involved the removal of about 14 ft. of sand, clay, gravel, and boulders, and from 1 to 3 ft. of ledge rock. The total quantity of earth excavated from the canal and wheel-pit was 85 000 cu. yd. Most of this earth excavation was well adapted for steam-shovel work, but that method was used by the contractor for only a small part of the work, most of the material being removed by pick and shovel and hauled to the dump in 1-yd. wagons.

Wheel-Pit.

Although the general location of the plant predetermined the generation of the power by wheels placed in an excavation and discharging through a tunnel having an outlet below the Falls, yet the form of such an excavation was dependent on the question of vertical or horizontal shafts for the machinery. This problem was decided in favor of vertical shafts, not only because of the greater convenience in operation afforded by having the generators on the power-house floor, but because of the practical difficulties which would be encountered in arranging the machinery for easy dismantling if horizontal shafts were used. The fact that no excavations of similar depth had been made on the Canadian side of the river introduced an uncertainty as to whether a wheel-pit could be made sufficiently dry to maintain electrical machinery successfully therein. On account of these and other considerations, it was determined to use units with vertical shafts, the spacing of the units to be 48 ft. The length of the wheel-pit was fixed at 566.84 ft. and the depth, to meet the tunnel grade, 171.1 ft. below the power-house floor, the width of rock excavation being 20.5 ft. The maximum depth of rock excavation was about 153 ft., the total quantity of rock excavation in the wheel-pit proper being about 226 000 cu. yd. To insure close adherence to the limits

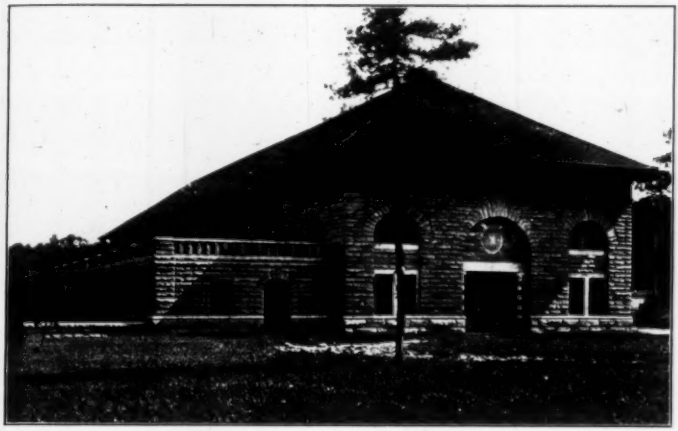


FIG. 1.—NORTH END OF POWER-HOUSE.

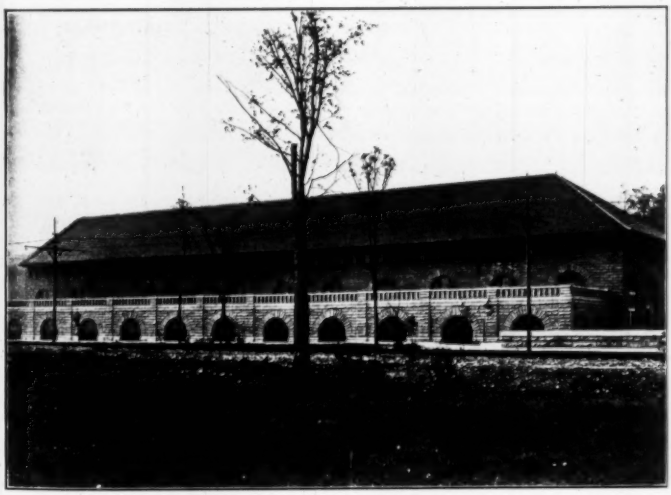
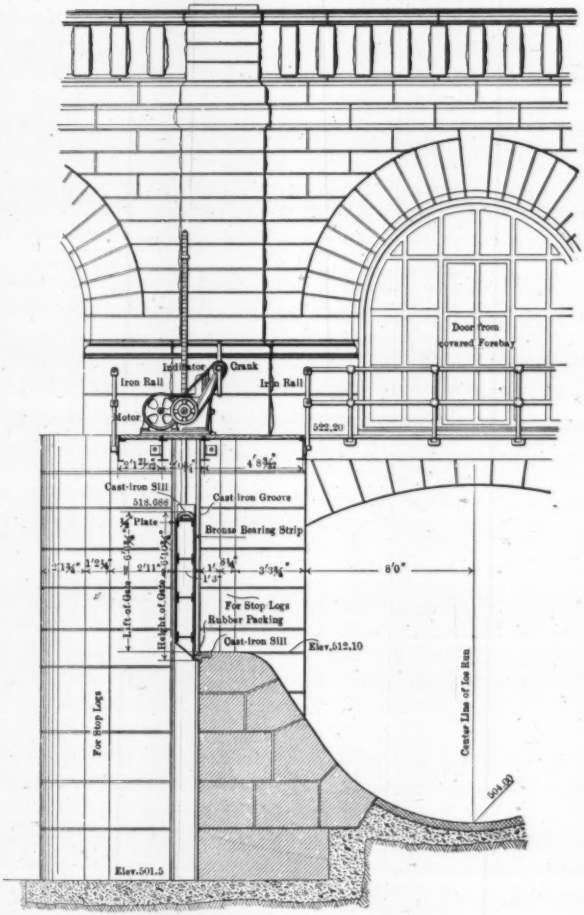


FIG. 2.—VIEW OF POWER-HOUSE FROM THE EAST.

SLUICE GATES FOR ICE-RUN
CANADIAN NIAGARA POWER COMPANY
PLAN SHOWING GENERAL ARRANGEMENT



SECTION LOOKING WEST

FIG. 4.

of excavation, and to prevent the shattering of the rock, and consequently the increased flow of water, the sides and ends of the pit were channeled. On account of the clearance requirements of the channelers, the cuts were made on an angle, a 6-in. offset being provided at the bottom of each cut of 6 ft. The rock was a limestone of varying character for two-thirds of the depth, and the lower third was shale.

Plate XXVI shows the completed wheel-pit, with the machinery installed, and also the lines of excavation and the brick lining walls. Above the turbine deck the average thickness of the lining walls is 15 in., and below that level it is 24 in., vitrified brick being used in the invert and a portion of the side walls. Fig. 1, Plate XXII, shows the rock walls, and the channelers at work, the pit having been excavated for about one-third of its depth when the photograph was taken. The brickwork seen in the upper left-hand part of the view is that built along the outside of a longitudinal recess cut into the rock at a water-bearing seam in order to collect the water. All the floor beams and girders shown on Plate XXVI rest on castings built into the side walls; the openings for these castings were gadded and broached. Excavations for the draft-tubes were treated in a similar manner. As the latter recesses were 51 ft. by 10 ft. 6 in. by 7 ft. 10 in., and were in close proximity to other checks, their excavation was a matter of no little difficulty. Four chambers, 21 ft. wide, 50 ft. long, and of varying depths, were cut into the east side of the wheel-pit to provide for the installation of auxiliary machinery, such chambers being lined with brickwork 2 ft. thick.

The excavation of the wheel-pit was let in two contracts, the first covering a length of only 270 ft. The final blasting in the second section of the pit was not completed until July, 1905, or 6 months after the plant was put in operation. It was necessary, therefore, to take great care, in blasting in the extension, to avoid disturbance of the alignment of the machinery. The movement of the wheel-pit walls was also increased by the excavation in the extension, and, although no serious results followed, the conditions, for the time being, were very undesirable. As the tunnel work was in advance of the wheel-pit excavation, an effort was made to save time by carrying it under a part of the wheel-pit. This excavation shattered the side walls, and it is questionable whether anything was gained by this method.

The bottom of the wheel-pit was given a grade of 3% in order to

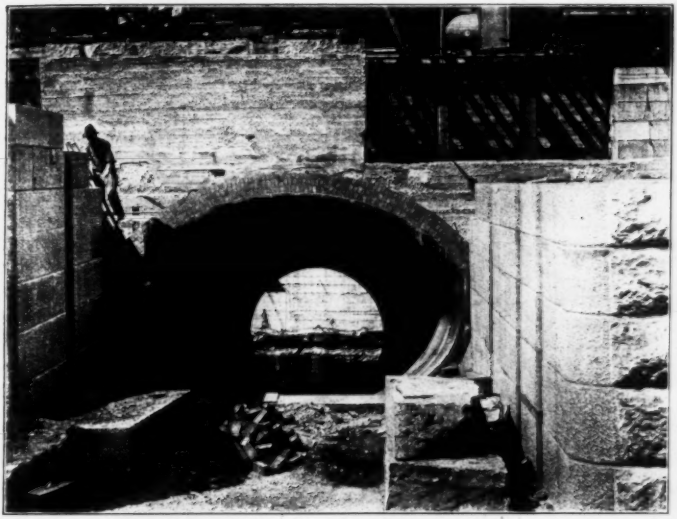


FIG. 1.—BRICK RING AROUND NO. 1 PENSTOCK MOUTHPIECE.

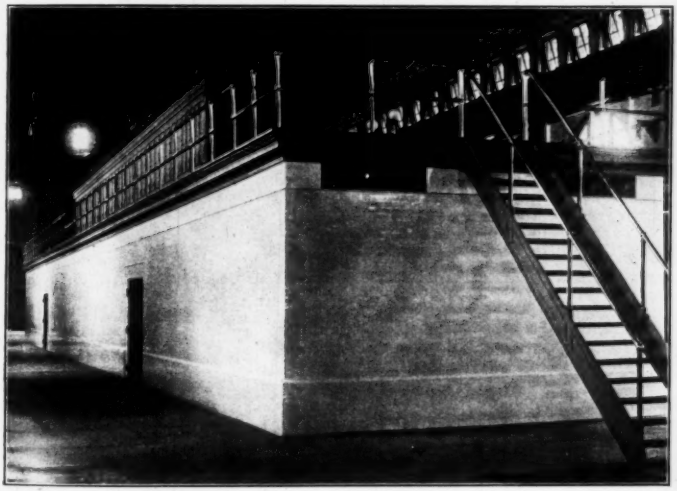


FIG. 2.—INTERIOR OF POWER-HOUSE, SHOWING ENCLOSURE FOR OIL SWITCHES.

equalize as fully as possible the velocities in the discharge water in the wheel-pit. To preserve an absolutely uniform velocity, with all the wheels in operation, would require that the width of the invert should decrease toward the south end, but such a design would have involved many complications not justified by the advantage to be gained.

The upper part of the wheel-pit, to a depth of from 25 to 30 ft. below the power-house floor, is lined with a retaining wall, the upper portion of which is faced with first-class, close-pointed masonry, while the lower part is of concrete. In connection with this upper lining wall, were built the arches, 24 ft. in length, supporting the stationary part of the generator. These may be seen on Plate XXVI.

The six floors in the wheel-pit require little comment; there are also platforms around the shaft at four other levels. Access is thus provided for the inspection and repair of all bearings and shaft couplings. The principal decks are covered with "Never-Slip" plate; the platforms and lower deck are composed of rack-bars. All main cross-beams are carried on castings, to which they are attached in such a way as to permit the freedom of motion required by the movement of the wheel-pit walls.

Tunnel.

The general alignment of the tunnel is shown on Plate XXIII, which also indicates the completed plant and its relation to surrounding objects. The southerly tangent was of necessity in the prolongation of the wheel-pit, and it was also desirable that the alignment at the portal should be approximately at right angles to the face of the cliff. The wheel-pit of the Niagara Falls Park and River Railway was to be avoided, and the portal could not be placed beneath its discharge tunnel. The rock formation at the point selected seemed most satisfactory. These conditions resulted in a tunnel 2 164 ft. long, the alignment consisting of 48% tangent and 52% curvature with a radius of 650 ft. The location of the portal is shown by Fig. 2, Plate XXII, which serves to give a very clear impression of the difficulty of carrying on work at this point. Owing to the prevailing direction of the wind, the heavy spray from the Falls fell on the work almost constantly; ice commenced to form in December, and lasted until May, and high water covered the work almost completely

at times. The tunnel cross-section finally adopted was of horse-shoe form, 25 ft. high and 18.84 ft. wide at its widest point.

The original intention had been to use four rings of brickwork throughout, but, as built, they were used for the arch only, the remainder of the lining being of concrete with only a facing of hard brick. Doubtless some advocates of concrete would have been willing to dispense with the brick entirely, even with tunnel velocities of 30 ft. per sec., but the perfect condition of the brick lining in the tunnel of The Niagara Falls Power Company after seven years of service was a strong argument in favor of the use of brick.

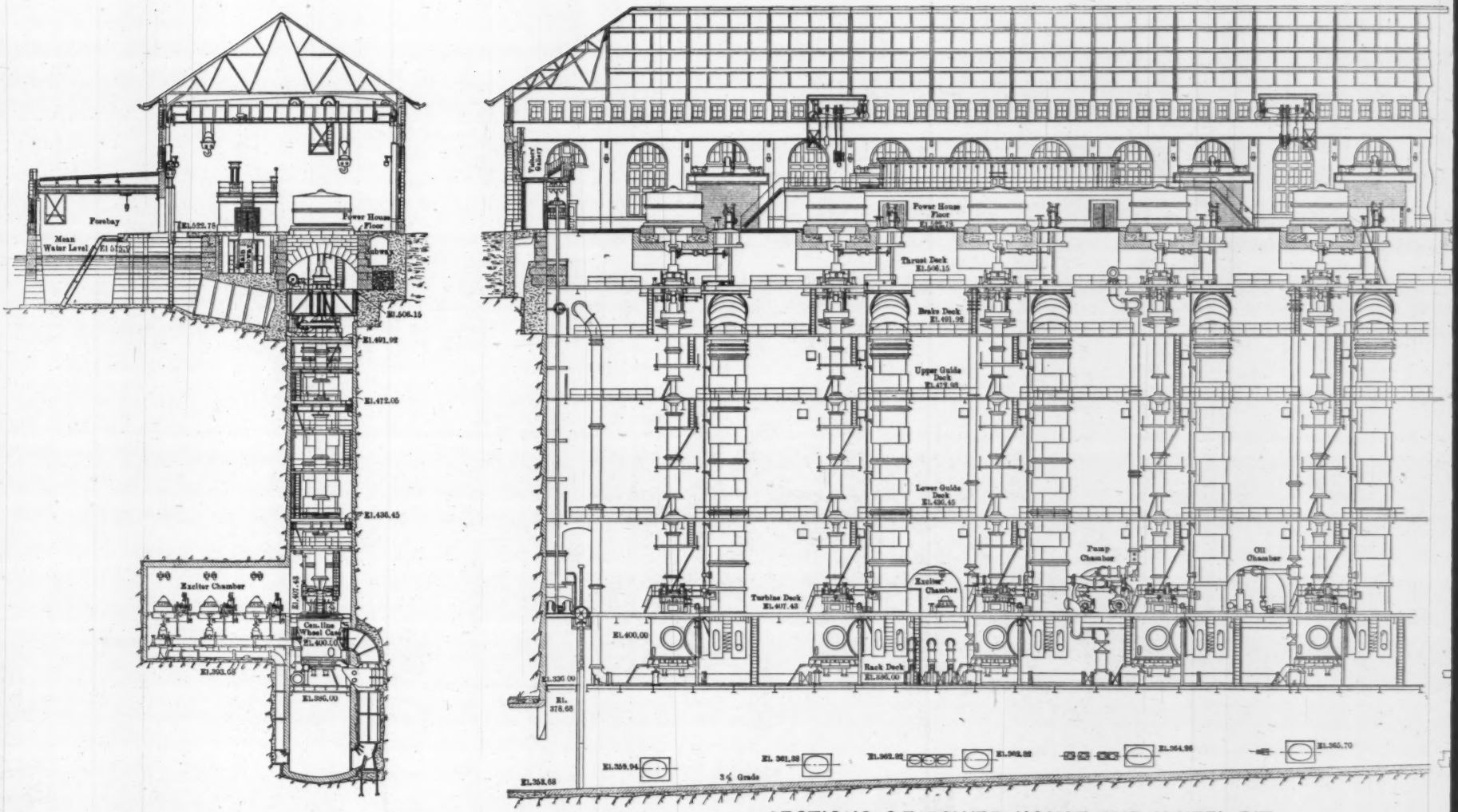
The gradient of the tunnel is 7 ft. per 1 000, except near the portal where it falls 11.2 ft. in 103.08 ft., a reverse vertical curve, with a radius of 248 ft. at the springing line, being used. The greater part of this portion is lined with granite blocks 2 ft. thick to withstand the increased velocity of the water.

After the removal of the coffer-dam between the portal and the river, it was found necessary to deepen the water channel. This was done in the summer of 1905 by an orange-peel bucket attached to a derrick, liberal quantities of powder being used.

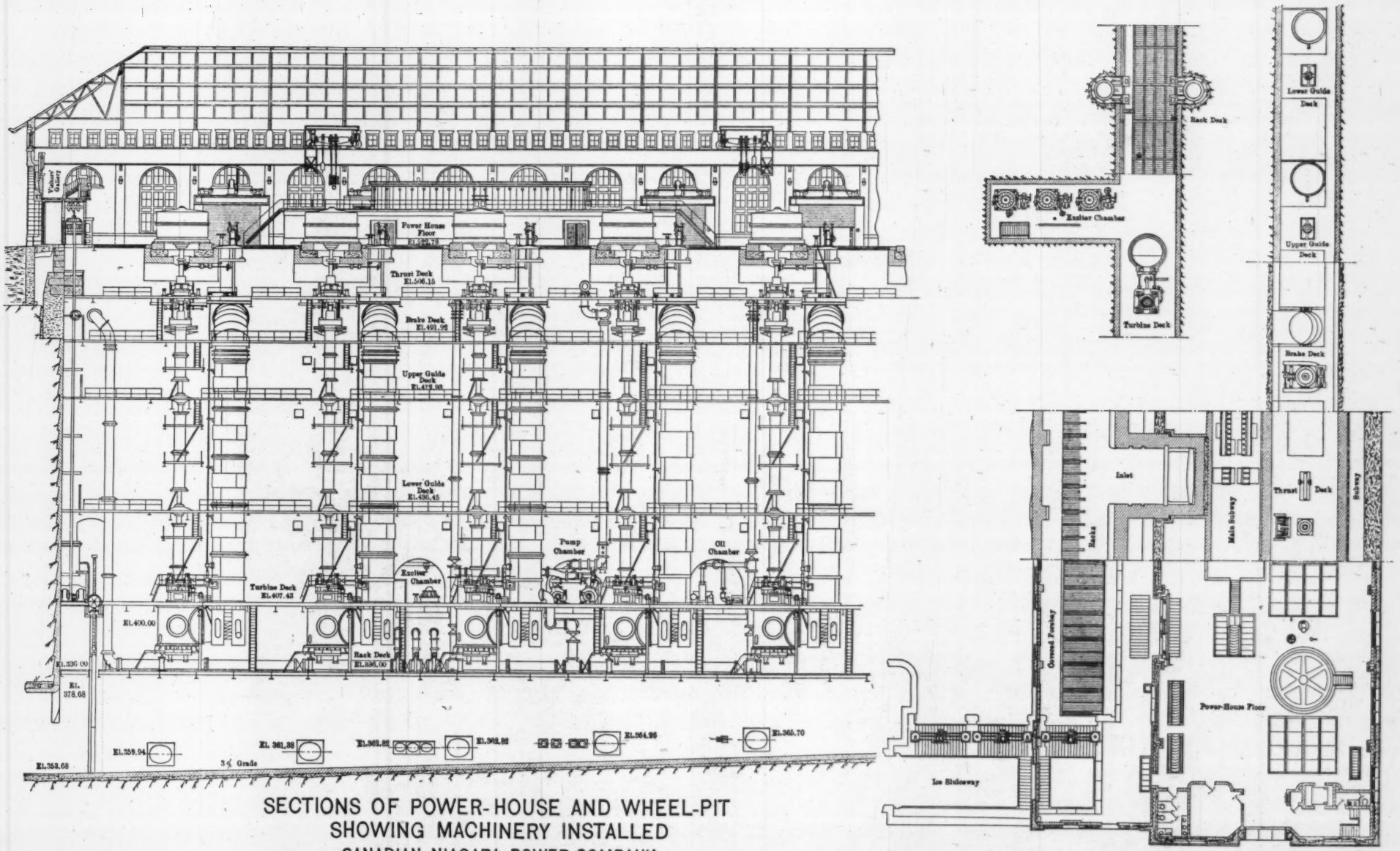
The excavation of the tunnel was carried in both directions from a shaft 1 470 ft. from the north end of the wheel-pit, and was also carried in for some distance from the portal. The section was removed as a heading and two benches, the timbering following the excavation of the heading as closely as possible. The excavated material was principally shale, which disintegrated rapidly upon exposure to air and moisture. Most of it was used in filling the lagoon adjoining Cedar Island.

The availability of the remainder of the material excavated from the tunnel, as well as the larger quantities removed from the canal and wheel-pit, enabled the Park Commissioners to consummate a plan which they had formed many years before and had partly carried out in 1895, namely, the reclamation of a large area of unsightly rock surface at the west end of the Horseshoe Falls left practically bare by the rapid recession of the apex of the falls and the consequent deepening of the central portion of the channel.* The filling of this

* The erroneous statement has been widely published that the crest line of the Canadian Fall has been shortened to the extent of several hundred feet by the power companies for their own benefit. The facts are as stated above. All the excavated material deposited within the Park limits was placed in accordance with the specific directions of the Park Commissioners. No power company has been affected, beneficially or otherwise, by the filling in of the portion of the river-bed from which the water had receded years before the power development began.



SECTIONS OF POWER-HOUSE AND WHEEL-PIT
SHOWING MACHINERY INSTALLED
CANADIAN NIAGARA POWER COMPANY



SECTIONS OF POWER-HOUSE AND WHEEL-PIT
SHOWING MACHINERY INSTALLED
CANADIAN NIAGARA POWER COMPANY

area made possible the construction of walks and driveways from which visitors may obtain a close view of the most impressive portion of the cataract, and has greatly improved the scenic conditions at this point.

Power-House.

The power-house superstructure is a fire-proof building, 110 ft. 10 in. wide, now completed for a length of 296 ft., to cover five units, its ultimate length being 588 ft. 8 in. The main power-room, covering the generators and switch-board, has a clear width of 68 ft. 2 in. and a height of 64 ft. 1 in. to the ridge. Along the east side of the building is the enclosed forebay, having a clear width of 36 ft. 6 in., the clearance line of the roof girders being only 14 ft. above the floor. This portion has a roof which is nearly flat, and is surrounded by an ornamental parapet wall.

The dimensions of the building and its relation to the wheel-pit and machinery were determined with great care. The dismantling of the large units, the conveyance of the parts to and from cars, and their temporary storage until the machines were re-assembled, were matters of no small moment, and diagrams were prepared to show the clearance lines of the larger parts when suspended from the two 50-ton cranes with which the building is equipped. The floor in certain sections of the power-house was designed to support the heaviest parts of the machinery arranged in that manner which, of all practical ones, would give the most severe stresses in the supporting beams, the portions of the floor thus designed being marked by brass plugs.

The roof, crane girders, and head-gate girders are carried on steel columns, encased in brickwork, projecting as pilasters into the power-room. The walls are of massive character, suitable for such an installation, being from 26 to 30 in. thick. The outside face is of Queenston blue limestone. This is one of the best limestones for building purposes, and has shown its excellent weathering qualities in the severe climate of Niagara Falls. The position of the power-house is peculiarly trying, as the spray from the Falls often freezes in a thick coating over its entire surface.

The roof is covered with semi-glazed green tile laid directly on steel purlins. It is believed that such a form of construction is somewhat novel for a building of such importance, and where the consequences of leakage would be so serious. The results have been entirely satisfactory, no leakage or condensation taking place since construction

ceased. The broad, overhanging, copper cornice combined with the shaded green of the roof gives a most pleasing effect. Figs. 1 and 2, Plate XXIV, show the building as now completed. Since the photograph shown in Fig. 1, Plate XXIV, was taken, the seal of the Company, designed by Macmonnies, has been cut in the stone over the front entrance. Bronze doors of ornamental design provide access to the power-house and to the visitors' gallery shown on Plate XXVI. Beneath this gallery is an office for the operating staff.

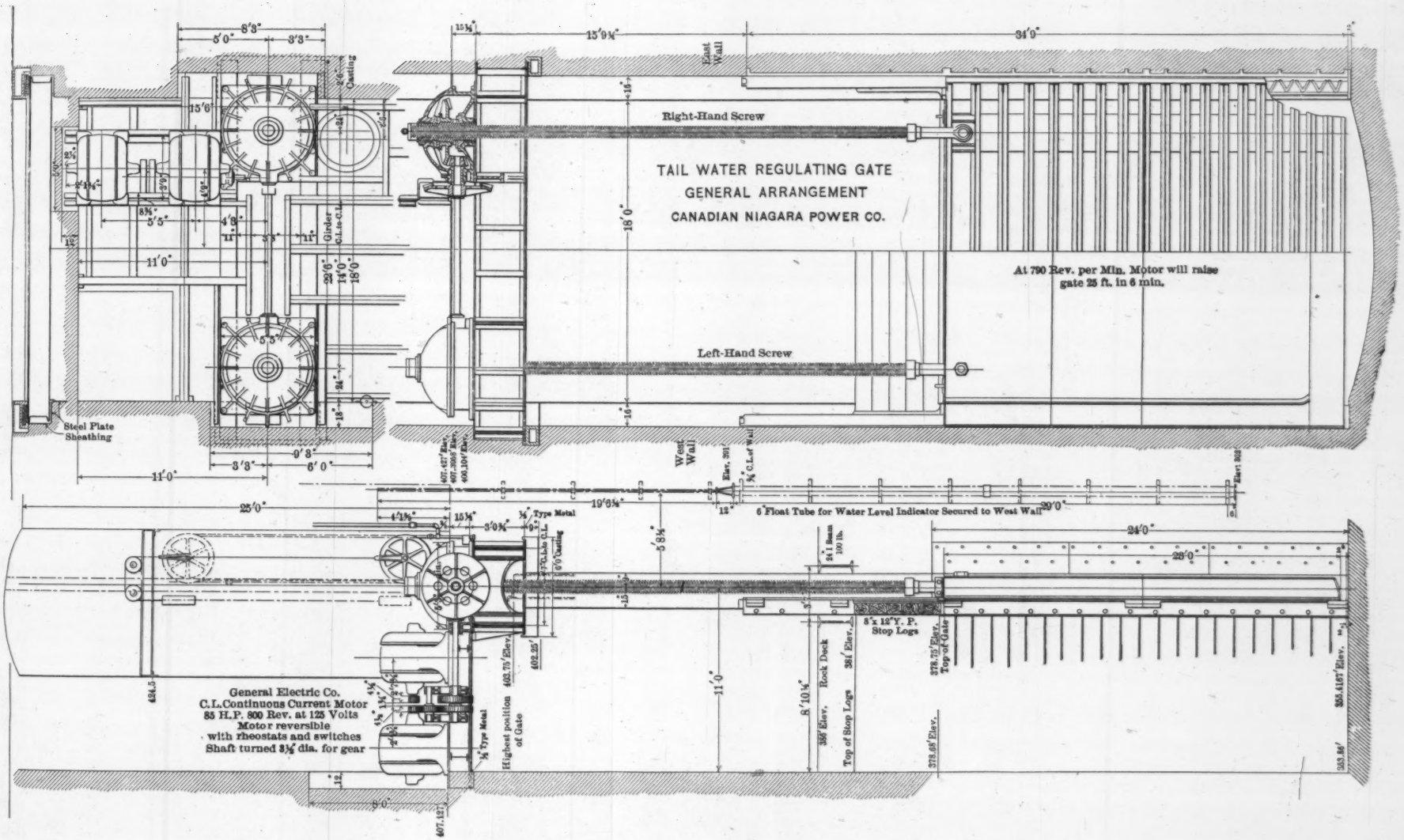
As shown on Plate XXVI, the space below the power-house floor is completely utilized. A subway, 5 ft. in width between the wheel-pit walls and the west foundation wall, provides for piping and auxiliary wiring and cables, and the main subway on the opposite side of the wheel-pit contains the bus-bar structure and the dynamos and feeder cables. On the east side of the subway, chambers between the inlets contain lockers for the employees, heating and lighting transformers, oil-storage tanks, etc.

The power-house is provided with two 50-ton electric traveling cranes, and these are used together for handling the armature of the generator, this piece weighing about 90 tons. A 5-ton, 3-motor, electric traveling crane in the forebay is used principally for moving racks and stop-logs.

A hydraulic passenger elevator furnishes access from the power-house to the several decks of the wheel-pit.

As shown by Fig. 2, Plate XXV, a structure, 127 ft. 6 in. by 17 ft. 6 in. by 11 ft. 7½ in., is built on the power-house floor to enclose the oil switches and to provide a foundation for the switch-boards as well as a working platform for the electricians-in-charge. This enclosure is of ornamental design, and is faced with white tile. Ducts are placed in the walls for carrying the wiring to the switches. Ducts beneath the power-house floor provide for carrying all cables between the generators and the main subway, as well as between the several subways and chambers. Pipes in the pilasters of the building carry wiring to the lights, so that all cables and wiring are concealed.

The view from the roof of the forebay is a beautiful one, the complete panorama of the upper rapids, the Horseshoe Falls, and the parks on both sides of the river being spread before the observer. It is doubtful whether, in any other locality, utility and beauty are combined in such a manner as in the power-plants at Niagara, or


TAIL WATER REGULATING GATE
GENERAL ARRANGEMENT
CANADIAN NIAGARA POWER CO.
Right-Hand Screw
Left-Hand Screw
East Wall
West Wall
At 790 Rev. per Min. Motor will raise gate 25 ft. in 6 min.
Steel Plate Sheathing
6" Float Tube for Water Level Indicator Secured to West Wall
8'x12" Y. P. Stop Logs
Rock Deck
Top of Stop Logs
Top of Gate
Highest position of Gate
General Electric Co.
C.L. Continuous Current Motor
85 H.P. 800 Rev. at 125 Volts
Motor reversible
with rheostats and switches
Shaft turned 3½" dia. for gear

where great resources are developed without marring the natural scenery.

Hydraulic Machinery.

The size and gradient of the tunnel having been determined, thus fixing its elevation at the point of juncture with the wheel-pit, the elevation of the working floor beneath the turbines, called the "Rack Deck," was selected so as to keep it above the surface of the tail-race water under all ordinary hydraulic conditions. The carrying capacity of the tunnel is calculated by using 0.01313 as the coefficient of roughness in Kutter's formula, and due allowance is made for the rise of water in the wheel-pit necessary to obtain the velocity maintained by the tunnel. At an early stage it was determined that draft-tubes were to be used, and, in order to keep their outlets submerged when only a small number of units were in operation, the controlling gate shown on Plate XXVII was installed. This gate is operated by an 85-h. p. motor, a duplicate motor being provided. The installation and correct alignment of a gate of this size, 23 ft. by 20 ft. 5 in., with a travel of 25 ft., at the bottom of an excavation 171 ft. deep, was quite difficult, but the gate has operated successfully. Indicators are provided to show both the height of the gate and the depth of the water. Although the gate is used daily in the operation of the plant, it has been found that the form and size of the draft-tubes are such that the vacuum is not broken if the outlets are uncovered, and, although the vacuum is not as steady as at other times, no interference with the usual operation would occur if the gate were temporarily inoperative. More particularly during the early operation of the plant, the water passed beneath the gate at a very high velocity, but at the last inspection it was found that no abrasion had occurred, although the vitrified brick invert was worn as smooth as glass.

The general form and arrangement both of the main and auxiliary machinery are shown on Plate XXVI. The water, after passing through the racks, enters masonry inlets, 18 ft. wide, through which it flows to the penstock mouthpieces. Descending into the wheel-pit through the penstock, the water passes into the wheel-case and thence through the twin wheels to a common central draft-chest from which it reaches the tail-race through draft-tubes built into each of the wheel-pit walls.

The total available head, under the usual conditions, will be 136 ft.,

but, with low water and peak loads, it may be reduced to 130.5 ft., and in preparing specifications for a sixth unit the latter figure was used.

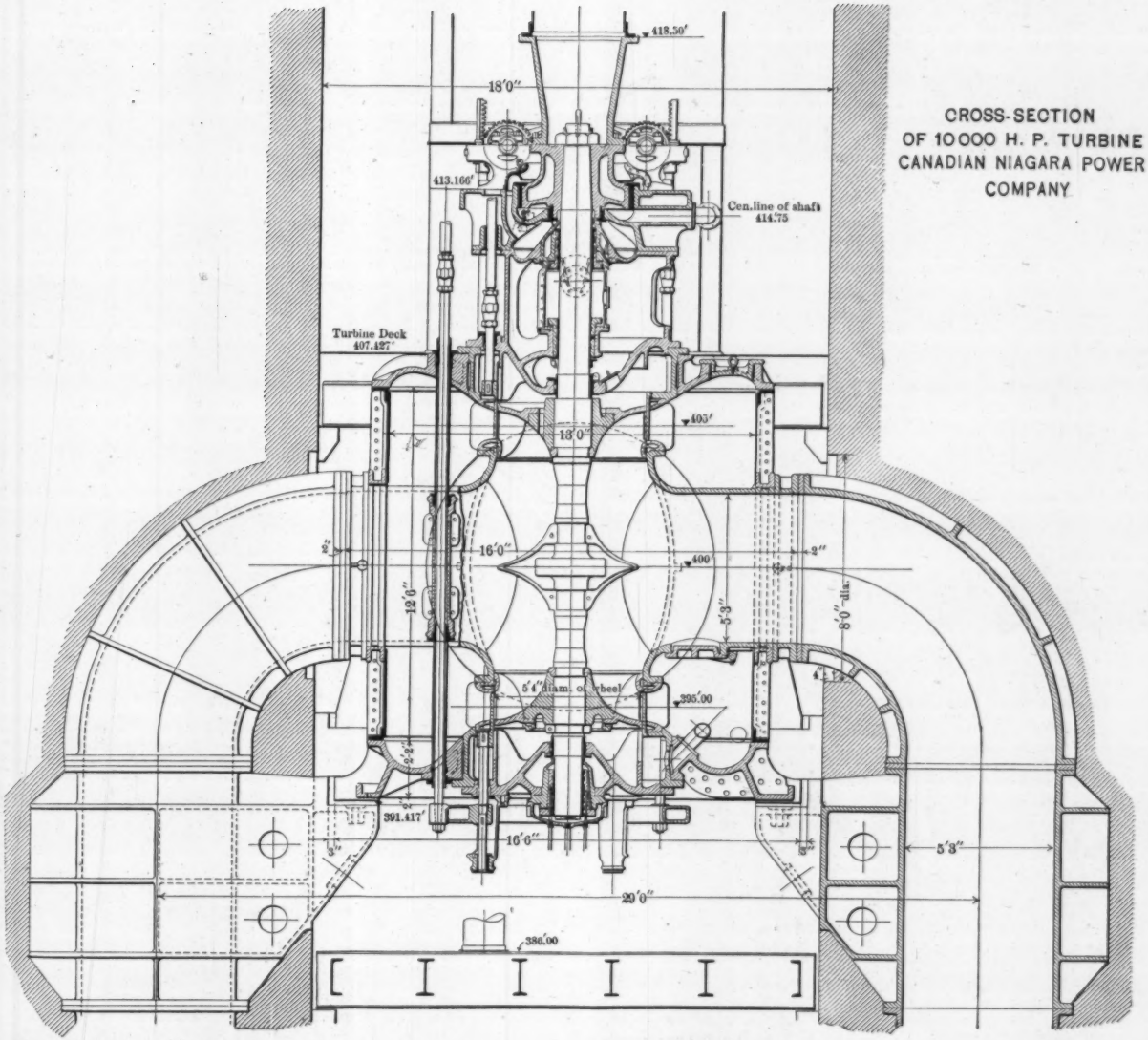
Careful consideration was given to the question of the speed of the units, and, for both hydraulic and electrical reasons, the machines were designed for 250 rev. per min. As the plant was to operate in conjunction with that of The Niagara Falls Power Company, it was necessary to furnish electric current of 25 cycles. The two speeds considered, therefore, were 250 and 188 rev. per min. The latter speed would have increased the weight of the revolving parts and added to the cost of the generator. Although it would have had the advantage of permitting the use of a single wheel, it had disadvantages from the standpoint of the hydraulic design. Experience has confirmed the wisdom of the selection of 250 rev. per min.

The penstocks were made 10 ft. 2 in. in diameter, the maximum size which could be transported on cars to the site of the plant, with flanges left for attachment in the field. The resulting velocity will be 11.2 ft. per sec. when 10 000 h. p. is being developed under minimum head. The entrance to the penstock is bell-shaped, and its axis is inclined at an angle of 11° 7′ with the horizontal. It is composed of cast-iron segments, and an idea of its size is given by Fig. 1, Plate XXV, which shows it in place before the end wall of the inlet was built.

The lower penstock elbows are interesting as examples of large steel castings, the over-all dimensions of the complete elbow being 12 ft. 11 in. by 13 ft. 6⅝ in. by 16 ft. 6 in. In order to transport the elbow, it was necessary to make it in two parts, as shown on Plate XXVI. The total weight of the complete elbow is more than 90 000 lb. These castings, for all five units, were made at the Skoda Works, in Pilsen, and, by their smoothness and accuracy of dimensions, illustrate the perfection there attained in work of this character. It may be interesting to note that the test pieces prepared from coupons attached to these castings showed as a maximum the following physical characteristics:

Elastic limit, in pounds per square inch	49 200
Ultimate tensile strength, in pounds per square inch	83 600
Elongation in 2 in	29.8%
Contraction of area	59.0%

PLATE XXVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXII, No. 1097.
VAN CLEVE ON
THE CANADIAN NIAGARA POWER PLANT.



CROSS-SECTION
OF 10 000 H. P. TURBINE
CANADIAN NIAGARA POWER
COMPANY

Considerable thought was given to the design of the draft-tubes, as the conditions affecting their installation were peculiar. As finally made, they are uniformly 5 ft. 3 in. diameter, and when the unit is running under full load the velocity therein is about 21 ft. per sec. While this high velocity represents a material loss, not only in velocity head, but also in friction, it is useful in imparting to the discharge water a part of the velocity required in the tunnel, the lower section of the draft-tubes discharging at an angle of 45° with the axis of the wheel-pit. To have made the cast-iron draft-tubes sufficiently large to reduce the velocity to the usual limits would have increased the expense greatly, and the conditions are not favorable for the use of concrete-lined draft-tubes. Plate XXVI shows the form of the tubes and the method of supporting the wheel-case on the section immediately below the upper elbow, and Fig. 1, Plate XXXII, gives an idea of the appearance of the lower elbow in the wheel-pit before bricking in.

Plate XXVIII, a cross-section, and Plate XXIX, a longitudinal section, show the general arrangement of the several parts. It will be seen that two Francis turbines are used, the water passing from the steel-plate wheel-case to a common cast-iron draft-chest. The regulation is effected by cylinder gates operated by a system of racks and gears actuated by a rod from the governor which passes down the pit along the penstock. The efficiency at partial gate openings might be greater with a regulation by movable vanes in the distributors, yet the practical difficulties of their operation in the space available would be great. Experience has shown that the accurate fit of the cylinder valves between the distributors and the turbines and their accurate guidance is a matter of the greatest importance. Clearances at these points cause vibrations which are most injurious.

The wheel-case and penstock elbow were adjusted to their exact elevation by jack-bolts attached to the supporting castings, and were secured in place by type metal. Space was also provided for horizontal adjustment, and blocks of type metal are used between the vertical faces of the wheel-case base and the corresponding surfaces on the draft-tube brackets. On Plate XXVIII it will be seen that a space of 2 in. was left between the vertical faces of the flanges on the draft-chest and on the draft-tube, and the draft-tubes were set accordingly, Before Units Nos. 4 and 5 were set, this space was much reduced by

the inward movement of the wheel-pit walls, and slip-joints were provided for all the units at these points, so that while the vacuum is maintained the flanges are free to move.

The turbine shaft, like all other portions of the solid shafting, is made from oil-tempered nickel steel having an elastic limit of 65 000 lb. per sq. in. It is guided by three bearings, two above the upper runner and one below the lower runner, the shaft being divided into two parts for convenience in dismantling. Difficult features of the design are: to prevent the escape of the oil used for lubricating these bearings, and to keep water out of the oil. Though not thus shown on Plate XXVIII, this is done by the use of cup-leather packings, it having been found that hemp packings scored the shafts.

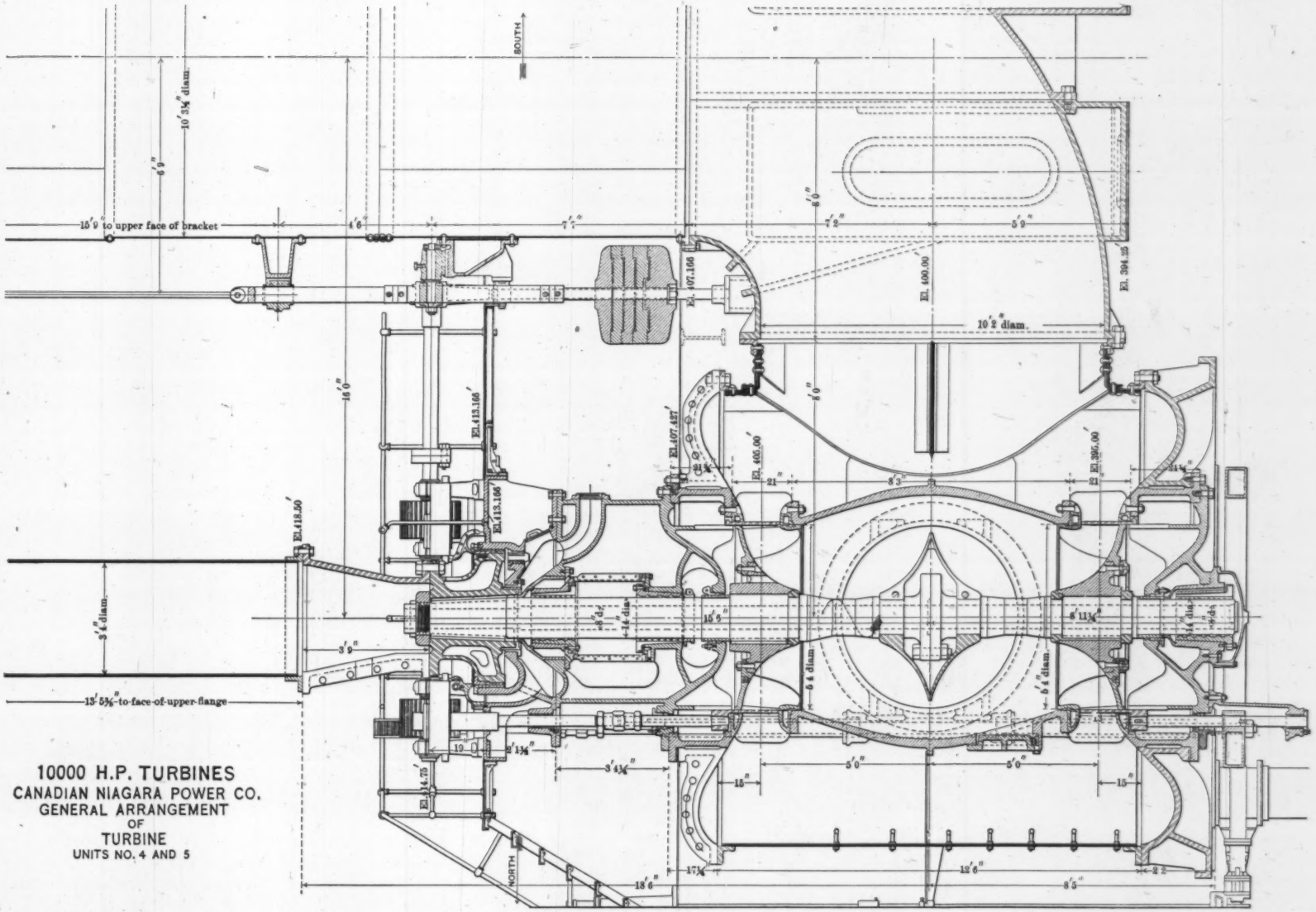
The runners and distributors are of bronze which, for Units Nos. 4 and 5, shows the following physical and chemical properties:

Elastic limit, in pounds per square inch	15 500
Ultimate tensile strength, in pounds per square inch	31 400
Elongation in 2 in	25.6%
Copper	88 %
Tin	10 %
Zinc	2 %

The bronze for the runners on Units Nos. 1, 2, and 3 contained some lead, and a recent specification by the writer requres 85% of copper, 10% of tin, 3% of lead, and 2% of zinc.

Special interest attaches to the method of supporting the revolving parts of the hydraulic and electrical machinery, weighing 240 000 lb., moving at the rate of 250 rev. per min. By reference to Plate XXVIII, it will be seen that by means of an opening in the wheel-case base ring, surmounted by an elbow, water passes to the space below the lower runner, which is thus under the full wheel-case pressure. The space above the upper runner communicates freely with the draft-chest through the openings shown on Plates XXVIII and XXIX, and pressure, therefore, cannot accumulate there from the water which leaks past the upper circular valve. With this arrangement, the upward pressure beneath the lower runner is not balanced by a pressure above the upper runner. Openings were provided for supplying the chamber beneath the lower runner with water from an outside source, but they have not been found necessary.

PLATE XXIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXII, No. 1097.
VAN CLEVE ON
THE CANADIAN NIAGARA POWER PLANT.



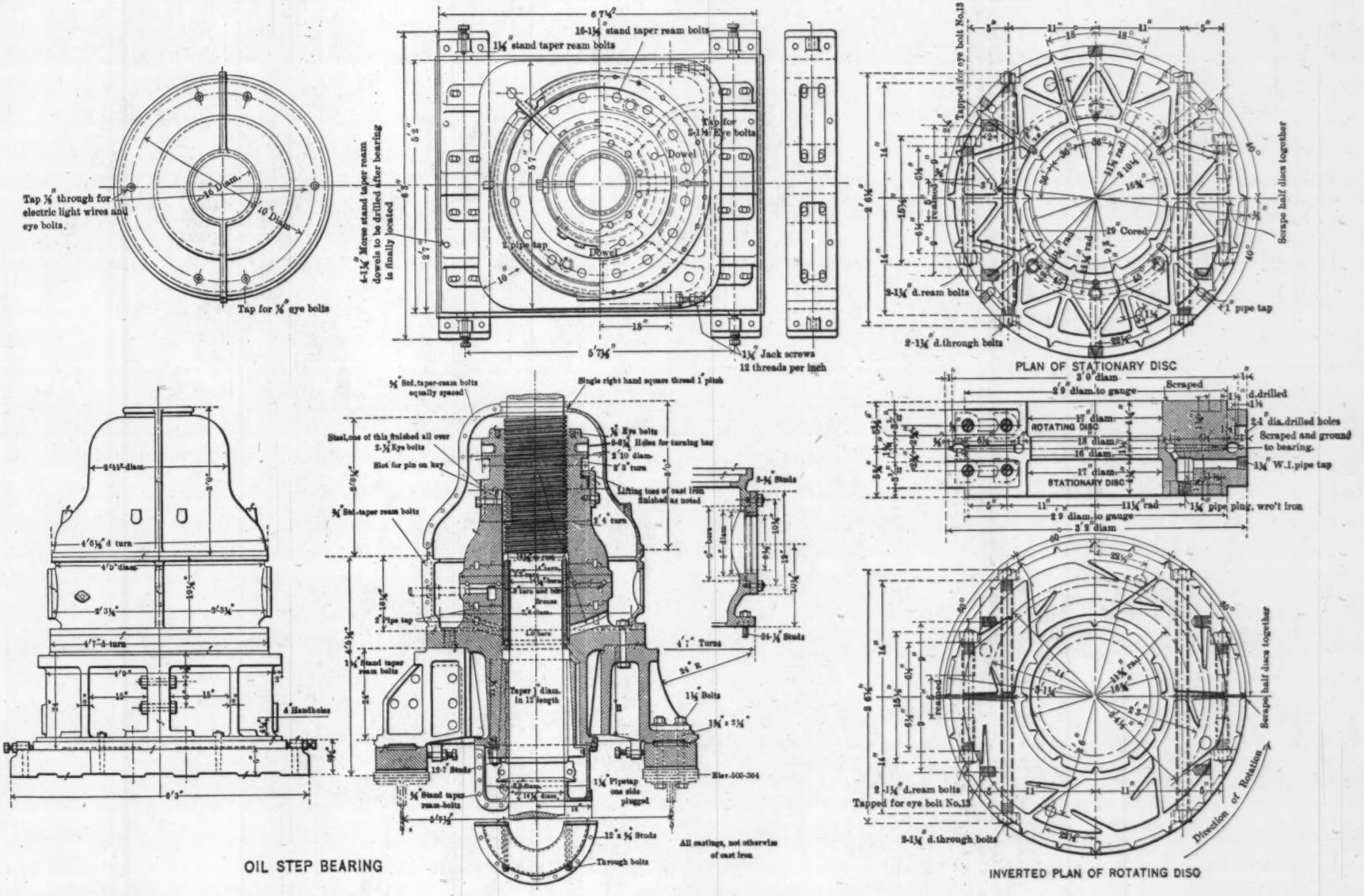
10000 H.P. TURBINES
CANADIAN NIAGARA POWER CO.
GENERAL ARRANGEMENT
OF
TURBINE
UNITS NO. 4 AND 5

The upward pressure thus provided for is not sufficient to support the entire rotating weight, and additional balancing pressure is effected by the piston shown immediately above the upper bearing on Plates XXVIII and XXIX. A 12-in. pipe is carried down the wheel-pit to connect by two 6-in. pipes with opposite sides of the space beneath the piston, an emergency connection being made with the wheel-case. The outside diameter of the piston being 3 ft. 10 in. and the inside diameter 21½ in., there is thus an area of 1 298 sq. in. subjected to the pressure of the water, which is about 43 lb. per sq. in. The water which leaks out at the inner and outer circumferences—where a clearance of $\frac{1}{32}$ in. is provided—is carried away by the drain pipe shown on Plate XXIX. Valves provide means of regulating the pressure under the piston. Bronze sleeves and bushings are placed on the moving and stationary parts at the periphery of the piston.

It would be possible, of course, to design the balancing piston so that, in conjunction with the pressure under the lower runner, it would exactly balance the weight of the revolving parts under a given condition of load on the unit and given elevation of tail-water; but such conditions are changing, and provision must be made, not only to take care of their variations, but also to provide for failure of the water pressure under either the balancing piston or the lower wheel, or under both. This has been done by the installation of an oil step bearing, placed at the deck immediately below the power-house floor, and supported by the heavy girders shown on Plate XXVI. It consists of two disks of charcoal iron, one stationary and the other secured to the shaft, oil being forced between these disks by a special pump driven from the main shaft. As much interest has been manifested in these bearings, by visitors at the plant, they are shown on Plate XXX. It will be seen that a guide-bearing is placed just below the step-bearing, the oil-catcher and up-thrust ring being shown at the bottom of Plate XXX. The stationary disk is attached by dowels to a receptacle having a spherical seat, the latter being provided to compensate for any errors in alignment and for adjustment to obtain even distribution of oil. The nut on the shaft permits the accurate setting of the upper disk. The outer cover protects the several parts, and acts as a receptacle for the oil. The cast-iron base is set with the upper finished surface at the proper elevation, and type metal is then poured between it and the top of the girders.

Adjusting screws permit the correct alignment of the bearing, after which it is doweled to its final position. The bearing-disks are made in halves, scraped together, and united by two bolts on each side, the joint preferably being tongued. The disks are made from the best quality of iron obtainable, the tensile strength being as high as 34 000 lb. The bearing surfaces contain two annular grooves, the outer one 1½ in. wide and the inner one 1 in. wide. They are connected by radial grooves, and the surface is still further subdivided by other grooves making an angle of 45° therewith. As will be seen on Plate XXX, oil is admitted to two cored channels extending about 100° on opposite sides of the bearing, being fed therefrom through three openings to the inner annular space. The oil is carried to all parts of the bearing, and escapes at both the inside and outside periphery. As the pump supplying the oil is of the three-plunger pattern, moving at constant speed, the bearing acts automatically, the pressure of the oil corresponding to the weight to be lifted. These bearings have never been called upon to carry the entire rotating weight, but it is believed that they would do so successfully. Unit No. 1 was operated for some time with the balancing piston removed, and Units Nos. 4 and 5 were each run for 1 hour with the balancing piston pressure cut down to 5 lb., the rise in the temperature of the oil being only 4°, 1 gal. of fresh oil per minute being admitted to the suction tank of the pump. The pressure of the oil rose to only 110 lb. per sq. in., although the pumps are capable of exerting a pressure of 500 lb. per sq. in. In the writer's opinion, the success or failure of an oil step bearing depends fully as much on the workmanship as on the design. In the bearings now being described the surfaces of the disks were finished and the grooves cut; then they were ground and scraped, and finally the surfaces were ground together with flour of emery, followed by chalk. It is also very important that the backs of the disks be scraped to an accurate bearing on their receptacles.

An interesting question arose as to the maximum capacity of a prime mover, of the general design of the present units, under the conditions imposed by the existing construction of penstock elbows and draft-tubes. The total loss of head in the unit, under various load conditions, had been determined by the Pitot-tube method, yet, in order to solve the new problem, it was necessary that the total head lost should be differentiated and the loss determined in each section


Tap ⅜" through for electric light wires and eye bolts.
Tap for ⅜" eye bolts
16-1¼" stand taper ream bolts
1¼" stand taper ream bolts
Tap for 2-1¼" Eye bolts
Dowel
2" pipe tap
4-1¾" Morse stand taper ream dowels to be drilled after bearing is finally located
1¼" Jack screws 12 threads per inch
Tapped for eye bolt No.13
Scrape half discs together
2-1¼" d.ream bolts
2-1¼" d.through bolts
1" pipe tap
PLAN OF STATIONARY DISC
ROTATING DISC
STATIONARY DISC
Scraped
2-1" dia.drilled holes
Scraped and ground to bearing.
1¼" W.I.pipe tap
1¼" pipe plug, wro't iron
OIL STEP BEARING
Steel, one of this finished all over
Slot for pin on key
Single right hand square thread 1" pitch
¾" Eye bolts
Lifting toes of cast iron finished as noted
Taper 1" diam. in 12" length
All castings, not otherwise of cast iron
Through bolts
INVERTED PLAN OF ROTATING DISC
Direction of Rotation

through which the water passes. Owing to the turns in the penstock and draft-tube, it was difficult to do this theoretically, and, therefore, on October 8th, 1907, an experiment was made in the following manner:

Pipes were connected with the penstock radially at four axial points just below the slip-joint near the upper elbow. Similar connections were made immediately above the lower elbow. The pipes from each elevation were united and carried to the upper wheel-pit deck where they were attached to glass tubes on gauge-boards. A pipe was also tapped into a connection with the forebay and another was connected with the gauge pipe attached to the wheel-case opposite the penstock elbow. The gauge-boards for these pipes were placed near those first mentioned, so that the four gauges could be read simultaneously. One of the draft-tubes was tapped at four points on the periphery, and the vacuum read on a mercury gauge. As the elevation of the water in the tubes surged rapidly, readings were taken every 5 sec. simultaneously on the several gauges, fifteen tests of 5 min. each being made with various loads on the generator. Six tests were made at practically full load, and the following shows the average distribution of the losses from the average total head of 134.56 ft. between head-water and tail-water:

From forebay to bottom of upper elbow	8.33%
In straight vertical portion of penstock	0.34%
In lower elbow and wheel-case	11.83%
Friction loss in draft-tubes	11.30%
$\frac{V^2}{2g}$ in discharge water	18.95%
In turbine wheel, and mechanical losses	49.25%
	100.00%

Curves were plotted to show the losses as segregated, and these were prolonged to determine the increased losses which would result from greater discharges. It was then determined that, with turbine machinery of the present design, in conjunction with existing draft-tubes and penstock mouthpieces, the maximum available power per unit on the turbine shaft would be about 11 500 h. p., and that beyond that point the losses would more than counterbalance the power con-

tained in increased quantities of water. This, however, should not be regarded as a criticism on the present design, as it performs efficiently the work for which it was intended.

Piping Systems and Auxiliary Machinery.

The lubricating and high-pressure oil systems are of complicated design, and only their more important features will be described.

Brass piping and bronze fittings are used throughout for the passage of oil, because of the increased carrying capacity and also the reduced chance of scale being carried by the oil into the bearings.

Lubrication is required for seven guide-bearings on each main shaft in addition to that necessary for the exciters. High-pressure oil is furnished to the step-bearing and governor of each unit by separate pumps. This is a departure from the method used in the oiling system in Power-House No. 2 of The Niagara Falls Power Company, upon which are modeled many parts of the lubricating system which is being described. In the American plant the same pumps supply both the lubricating oil and the high-pressure oil for the governors, but such an arrangement necessitated the installation of accumulators and special reducing valves.

For convenience in operation, and to avoid the placing of apparatus below the level of the water in the tail-race, the lubricating system is divided into upper and lower systems, the latter supplying the turbine bearings and the exciters, and the former the oil required by the remaining bearings. The oil-cleansing apparatus and pumps are in a brick-lined chamber cut in the rock on the east side of the wheel-pit near its middle. The chamber is in three stories, the main portion, 50 ft. 4 in. by 17 ft. 5 in., being at the level of the turbine deck, while the front of the chamber is carried to a depth of 24 ft. below that level in order to receive the drainage from the lower bearings.

Oil is brought into the power-house in a tank car, and is piped directly to storage tanks in a chamber beneath the power-house floor. From these tanks it is piped to the oil chamber at the turbine deck, fresh oil being admitted to the system as required. From the chamber the oil from the upper system is pumped to equalization tanks in the power-house roof, from which it passes to a main laid just above the thrust deck. With this main are connected at each unit two pipes, one leading to the generator bearings and the other to the remaining guide-

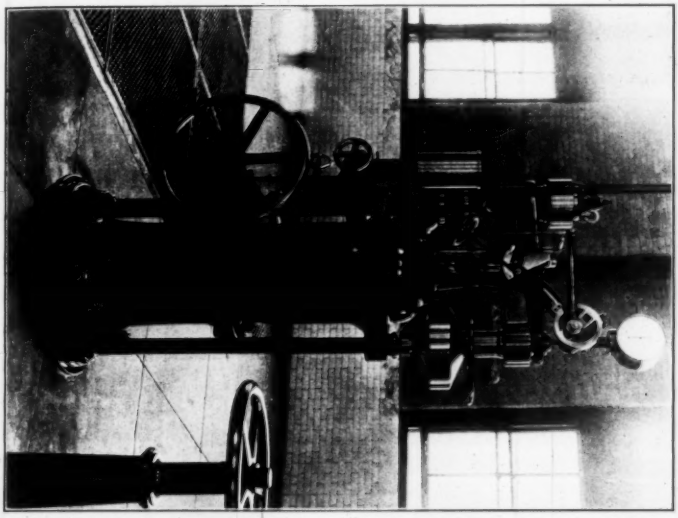


FIG. 1.—OIL-PRESSURE SINGLE-ACTING GOVERNOR.

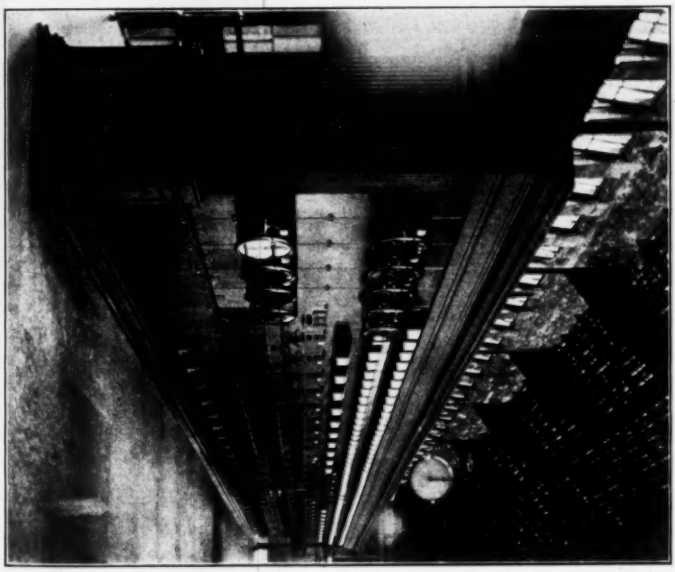


FIG. 2.—SWITCH-BOARD.

bearings of the upper system. Connections are provided for introducing fresh oil into the high-pressure system. Oil having passed through a given bearing is thrown into the oil-catcher and is piped to a funnel where its temperature may be observed. A drain pipe common to the discharge from the several bearings is provided at each unit, and leads to a horizontal pipe above the turbine deck, through which the oil is conducted to its chamber. Here it may be treated in one of three ways: 1, it may pass directly to suction tanks and thence be pumped by Quimby screw pumps to the equalization tanks in the power-house roof; 2, the oil may be filtered through cotton cloths in a given compartment of a four-chamber tank, heat being used as desired to assist in the deposit of the foreign matter; 3, the oil may be boiled to remove any excess of moisture, the oil being drained to cooling tanks before being filtered or pumped direct to the upper tanks.

The oil in the lower system receives a certain quantity of water from the lower turbine bearing, and therefore requires a different treatment from that of the upper system. The return oil enters one of two suction tanks, and is pumped by a motor-driven Quimby pump to a separating tank in the upper story of the chamber. This tank is provided with baffle-plates, which cause the oil to pass in a circuitous course, moderate heat being applied. If necessary to boil the oil to remove the residual water, it passes to the tank used also for the upper-system oil, thence to cooling tanks, from which it flows to a filter tank similar to that used for the upper system; thence it goes to the suction tank and is pumped to a horizontal supply main placed above the turbine deck and provided with a stand-pipe and overflow. By-passes are inserted, so that any of the purifying processes may be omitted when unnecessary. All apparatus is in duplicate, so that no interruption of the service may occur through failure of oil.

The high-pressure oil for the governor and step-bearing of each unit is supplied by a pair of triplex pumps, each having a capacity of 100 liters, driven from the main shaft and capable of supplying a pressure of 500 lb. per sq. in. The working pressure of the oil supplied to the step-bearing varies automatically with the load to be carried, and the pressure of the oil pumped to the governor is normally 225 lb. per sq. in. Complete cross-connections and relief valves permit either pump to be used on the governor or step-bearing at will,

and a main above the thrust deck enables a spare motor-driven pump of the same style to supply high-pressure oil to any unit when it is being started. If any accident should disable the motor-driven pump, oil from the pumps of a moving unit will supply one which is idle.

The governors for the main units are of the oil-pressure, single-acting type, shown in Fig. 1, Plate XXXI, and are patented by Escher Wyss and Company. A compression member connected with the piston in the main cylinder extends to one end of a lever on the thrust deck, and, from the opposite end of the lever, a rod, as already explained, passes to the rack and pinions operating the cylinder gates, a weight of about 7 000 lb. being attached to the lower end of the rod. The gates close by gravity and open by the oil pressure. As showing the accuracy of regulation which obtains, the following extract from the contract with the manufacturer may be of interest. It requires:

"(2)—That each and every governor to be manufactured hereunder shall give the following regulation, namely: When sudden changes in the load on the generator corresponding to the respective percentages of the total rated capacity of the generator which are set forth in the first column of the following schedule are made, the respective variations in speed above or below the normal shall not exceed the respective percentages of the said normal speed which are set forth in the second column of the said schedule, and the times which will elapse between the respective changes of load and the restoration of normal speed shall not exceed those respectively set forth in the third column of the said schedule."

" Changes in Load.	" Corresponding Maximum Speed Variation.	" Time of Perturbations, in Seconds.
25%	2%	25
50%	4%	35
75%	6%	50
100%	8%	60"

In testing the governor, the above percentages of load were thrown off with an oil-switch, thus making the tests as severe as possible. The regulation required when throwing off load was practically fulfilled, the regulation with the removal of partial loads being better than that required, while the increase in speed when the full load was thrown off was about 10% instead of 8 per cent. Greater perturbations in speed than those specified in the contract were caused by the sudden addition of loads, especially of large increments. This condition was

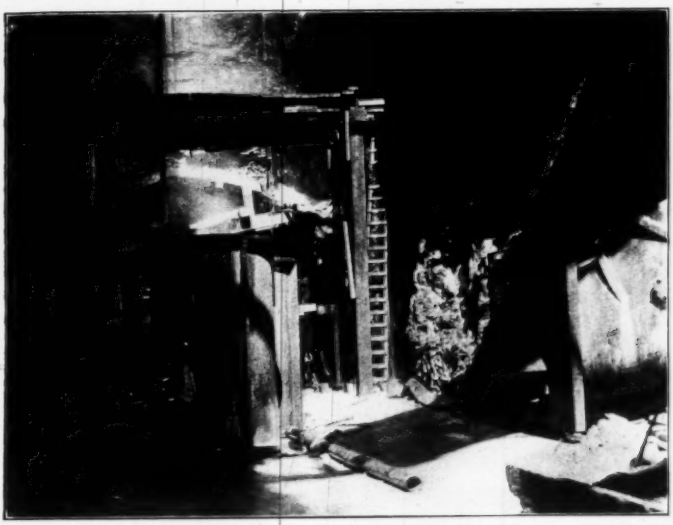


FIG. 1.—PLACING DRAFT-TUBES

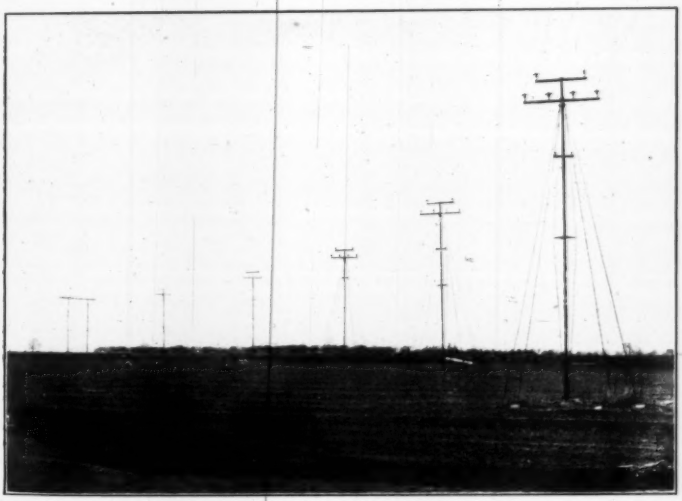


FIG. 2.—TRANSMISSION LINE.

due to the lack of oil capacity rather than to the governor action, and air-pressure chambers, supplied by a separate motor-driven air compressor, were installed on the oil piping, but have not been used, as, under the operating conditions of the plant, the instantaneous additions of large increments of load are most unusual. The regulation obtained has proven very satisfactory under operating conditions.

In the northerly chamber, at the level of the turbine deck, are installed three exciter units, each consisting of a 200-kw., 125-volt, vertical-shaft, direct-current dynamo, driven at 600 rev. per min. by a turbine of the Francis type. The direct current thus generated is used, not only for exciting purposes, but also for operating motors and for furnishing light and heat. The arrangement with vertical shafting permits the electrical machinery, switch-boards, and wiring to be located on the upper floor of the chamber, removed from the hydraulic machinery and piping, which are installed on the floor below, the draft-tubes occupying the space under the turbine floor. Except as noted below, all auxiliary machinery is supplied with water for power purposes from a 36-in. riveted-steel pipe connected with the north end of the forebay and laid along the rack deck. Branch pipes, provided with control valves, lead to the several turbines. Each exciter turbine has a separate supply pipe, thus tending to prevent a total shut-down. The 36-in. pipe is fed at various points by 24-in. pipes connected with the forebay.

As the continuity of the long-distance service is practically as dependent upon an uninterrupted supply of water to the transformers as upon the electric current, and as no reliable municipal source of water was available, it became necessary for the company to construct its own water-works system. Accordingly, there have been installed, in Chamber No. 2, two 3 000 000-gal., single-lift, centrifugal pumps, each of which is driven by a 174-h. p. Francis turbine. One of the pumps is also connected with a motor. As it is so important to provide against a shut-down, both suction and motor pipes are provided in duplicate. In addition to connections to the 36 and 24-in. pipes above referred to, pipes are also connected with the penstock on Unit No. 3, so that if, under any circumstances, the smaller pipes should become choked with ice, the penstock will be available as a source of supply. Provision is made for two additional pumps if they should be required. The pumps normally operate under a pressure of 137 lb.

per sq. in., but, by connecting them up in series, as may be done quickly in case of fire, the pressure can be raised to 225 lb. per sq. in. A 24-in. main carries the water to a point outside of the power-house where a system of pipes leads in various directions, the most important main leading to the transformer station and stand-pipe on the company's lands at the top of the escarpment. The stand-pipe, 30 ft. in diameter and 115 ft. high, is on a branch line in which is placed a motor-operated valve to be closed from the transformer station in case of fire. Provision is made for supplying with water the extensive factory sites owned by the company between the transformer station and Chippawa. A 4-in. main is secured to the wall above the thrust deck, and, at each unit, connections are taken off to the cooling coils in the generators and to hose outlets at the various wheel-pit decks and the power-house floor. Ample provision is thus made for extinguishing fire, although such precautions would seem to be in the nature of making assurance doubly sure, as the power-house and wheel-pit decks are absolutely fire-proof, practically the only wood being that in the southerly temporary end of the power-house, upon which a sprinkler system is installed.

In addition to the oil-treating apparatus already described, there is installed in Chamber No. 3 an air compressor operating at 140 lb. per sq. in., driven by a 7-ft. impulse water-wheel, the compressed air being used for cleaning out the generators and for operating various tools.

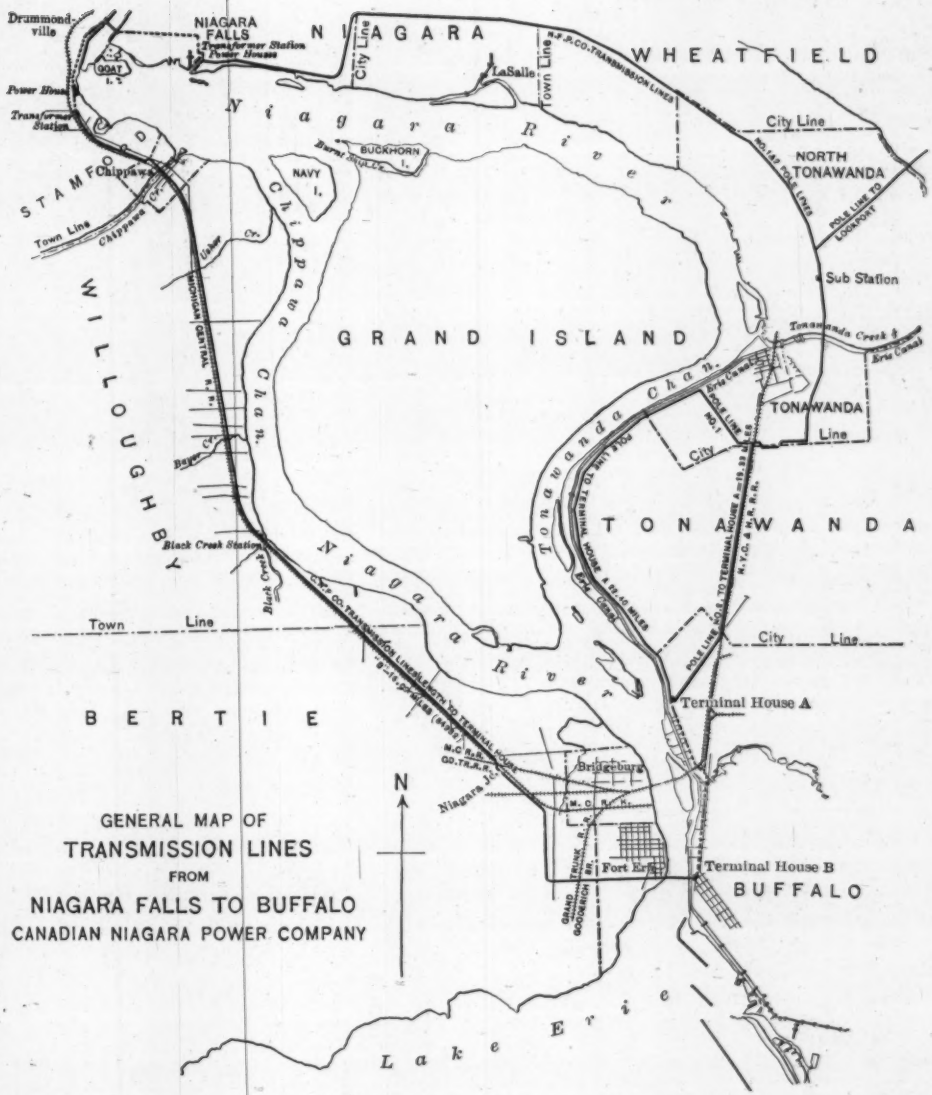
Electrical Installation.

Only a brief description will be given of the more important features of the electrical installation. For a more detailed account of this part of the plant, reference is made to an article* by Mr. H. W. Buck, who, as Electrical Engineer of the Canadian Niagara Power Company, has been in responsible charge of the design and installation of the electrical plant.

As shown on Plate XXVI, the generators are carried on stone-faced, concrete-filled arches, being secured to cut-stone foundations 6 in. above the power-house floor. The tops of these foundation stones were cut with great exactness after the turbine shaft was in

* *Proceedings*, Sixteenth Convention, Canadian Electrical Association.

PLATE XXXIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXII, No. 1097.
VAN CLEVE ON
THE CANADIAN NIAGARA POWER PLANT.



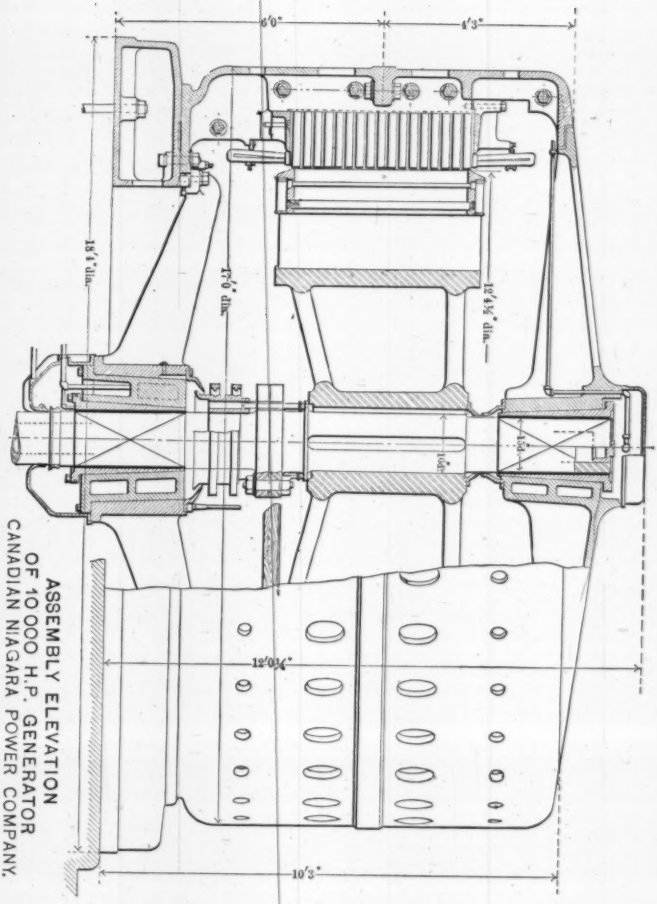


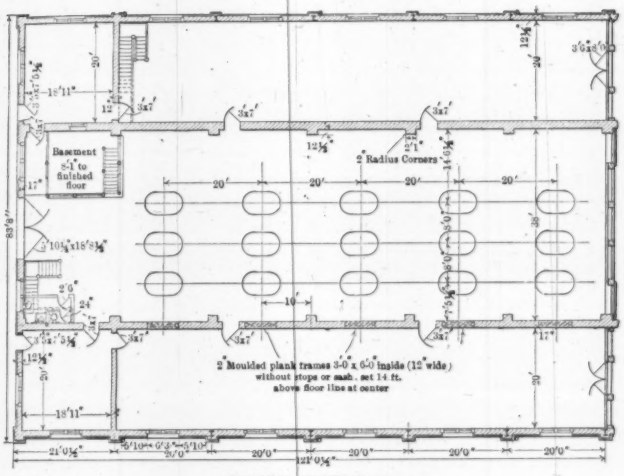
FIG. 5.

ASSEMBLY ELEVATION
OF 10 000 H.P. GENERATOR
CANADIAN NIAGARA POWER COMPANY.

place, as no grouting or other filling was placed between the generator base and the foundation.

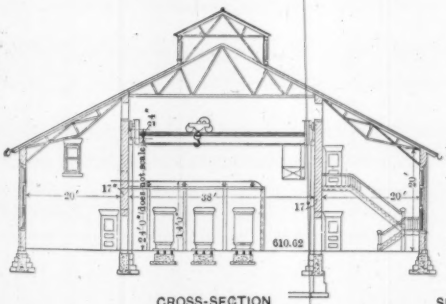
The generators are of the revolving, internal-field type, furnishing 25-cycle, three-phase current at 12 000 volts. The machines are rated at a capacity of 10 000 e. h. p., but they are capable of a large overload. The general construction of the generator is shown on Fig. 5. Exciting current at 125 volts is supplied to the collector rings immediately below the upper shaft coupling. From the generator the current is carried in ducts to the main subway and thence to double-throw selector oil-switches, through which it passes to the four sets of bus-bars. The oil-switches, in addition to their automatic action in case of short circuits, are operated by relay switches located on panels on the floor of the switch-board gallery shown on Fig. 2, Plate XXXI. The operating board contains five generator panels, twenty feeder panels, ten recording wattmeter panels, and three bus-bar interconnecting panels. Each panel is complete in itself, and contains no instruments except those belonging to the apparatus or feeders controlled thereby. The switch-board shown in Fig. 2, Plate XXXI, is designed to provide for five units, the remaining six units being governed by a second switch-board to be located opposite the eighth unit. The sixth unit, if installed in advance of others, however, will be controlled, at least temporarily, from the existing board. Emergency switches are provided by which the field current may instantly be thrown off the entire number of units should occasion require.

All the cables are carried singly upon grooved electrose supports secured to horizontal channels. In case of a short circuit, it is believed that no arc will form between the cables; and their thorough separation thus minimizes the possibility of trouble resulting from burn-outs. The cables are carried to a connection with the two main conduits, namely, that leading through the Queen Victoria Niagara Falls Park to the upper steel arch bridge across the Niagara River, and that leading to the transformer-house at the top of the escarpment. The former group interconnects the plants of the Canadian Niagara Power Company and The Niagara Falls Power Company. The current from the Canadian plant may be supplied directly to those tenants of the American company who use it at 11 000 volts; it may be raised to a voltage of 22 000 and sent to Buffalo; or, by using Scott

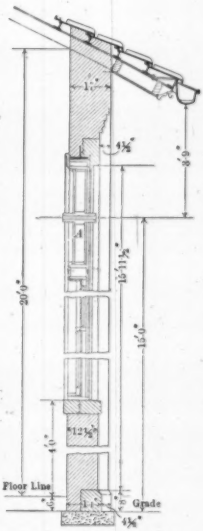


GENERAL FLOOR PLAN

FRONT ELEVATION



CROSS-SECTION



SECTION OF OUTER WALL

MAIN TRANSFORMER STATION

FIG. 6.

connected transformers, it may be reduced to 2 200 volts at two-phase, and the machines in the two plants operated in parallel.

The transformer station, located as shown on Plate XXIII, is a brick and steel structure, which is divided longitudinally into three sections, as indicated on Fig. 6. The east side contains the low-tension switches and air-cooled 11 000-2 200-volt transformers; the central bay contains the main, oil-insulated, water-cooled transformers; and in the west compartment are the high-tension switches and bus-bars. By this arrangement of the building, the several classes of apparatus are completely separated from each other, and, as the building is absolutely fire-proof, continuity of service is secured as well as possible. The main transformers, by which the voltage is raised for overhead transmission to Buffalo, are wound so as to be capable, with an 11 000-volt primary current, of giving a secondary current of either 22 000, 33 000, 38 000, or 57 300 volts. The first arrangement is now used, as the Canadian plant frequently operates in parallel on the Buffalo load with the plant of The Niagara Falls Power Company. All the wiring, however, is insulated to carry safely the maximum available voltage. The fifteen existing transformers have a total capacity of 25 000 e. h. p., the small size being adopted for flexibility in operation. This end having been attained, the transformers to be installed in the building when extended are planned to be of 4 167 e. h. p. capacity, it being contemplated to double the capacity of the station. In addition to water and drain pipes, provision is made for supplying oil to the transformers and drawing it to an air-tight tank through lead-lined cast-iron pipes. In case of emergency, the oil may be discharged from the transformers into a sewer. Such current as is required locally is transmitted overhead at 2 200 volts, only a small load of this character now being carried.

Conduits.

Two main trunk conduits, each containing 32 ducts, were built in connection with the power development of the Canadian Niagara Power Company. These are shown by broken lines on Plate XXXIII. The length of the conduit to the arch bridge is 6 500 ft., and of that to the transformer station, 2 200 ft. These conduits are of interest because of the arrangement of the ducts in groups of eight each, it having been found, in the experience of The Niagara

MANHOLE NO.1 ON CONDUIT FROM POWER-HOUSE TO TRANSFORMER STATION

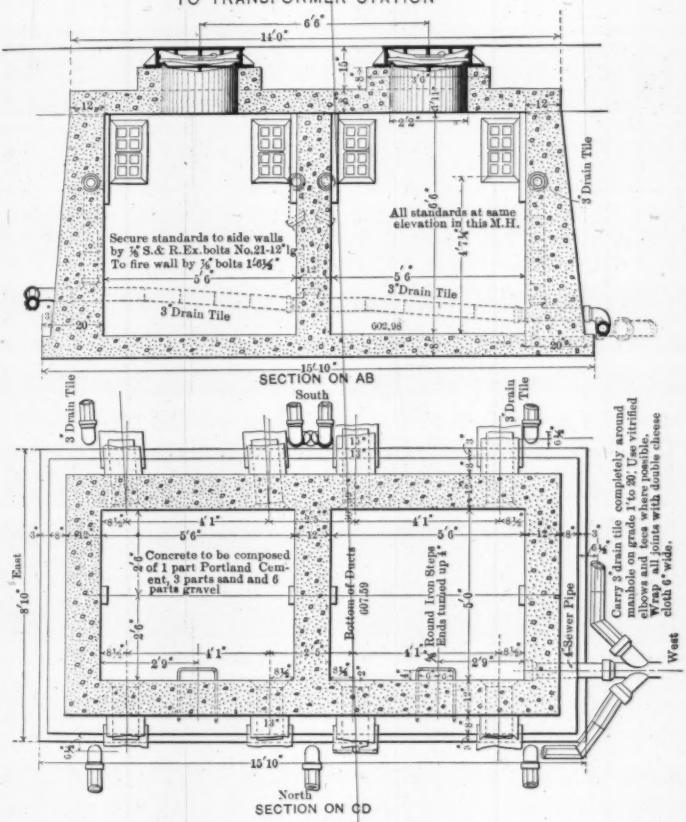


FIG. 7.

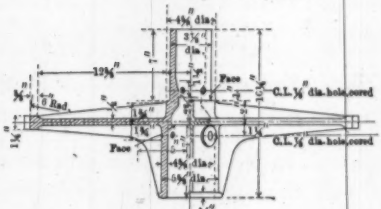
Falls Power Company, that injurious heating might be expected if ducts containing cables carrying large amounts of current were grouped in a mass, as has frequently been done elsewhere. The double manhole shown by Fig. 7 has proved very satisfactory. The results of a short circuit are minimized, the cables have a straight lead, with maximum splicing space, and the workmen have abundance of room. The advantages of this design, as compared with the elliptical and hexagonal manholes frequently used, are apparent.

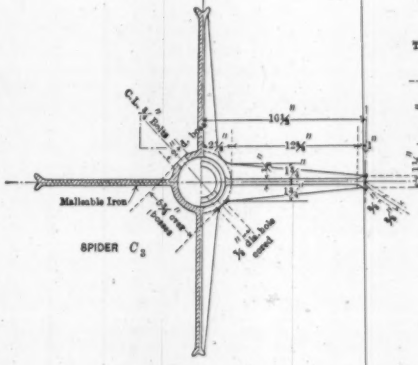
Transmission Lines.

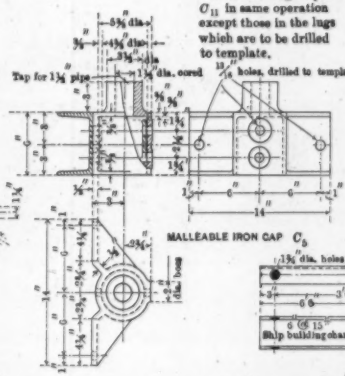
The output of the transformer station is now used principally in supplying 22 000-volt current to The Cataract Power and Conduit Company at a new station built near their load center in Buffalo. That company was formerly supplied with power by The Niagara Falls Power Company exclusively, but now has the advantage of duplicate service. The Canadian transmission lines are built on a private right of way, 30 ft. in width, following the route shown by Plate XXXIII from the transformer station to the Town of Fort Erie, Ontario, and thence by an overhead crossing of the Niagara River to Terminal House B, in Buffalo, a distance of 16 miles, as compared with 25 miles for the American transmission. One pole line containing two circuits is in service, and the building of a second line is now in progress. Each circuit has a rated capacity of 12 500 h. p. or a total transmitting capacity over the right of way of 50 000 h. p. at 22 000 volts.

Both the pole line and the overhead crossing contain several novel features which will be described briefly. The unusual form of pole used is that shown on Plate XXXIV. The central compression member consists of two 20-ft. lengths of 4-in. steel pipe, a cast spider with 33-in. spread being placed at the center, the pipe being stiffened with four $\frac{3}{4}$-in. sway rods. The tubular portion is stepped into a casting resting on a block of concrete. Longitudinal and transverse stresses are borne by four 1-in. guy rods attached to a casting bolted to the pole immediately below the lower cross-arm. These guy rods are anchored by concrete piers 12 in. square at the top and 18 in. square at the bottom. The soil was peculiarly adapted for this form of anchorage, as it consisted of a very hard clay which could be excavated only with great difficulty. Recent tests of an anchor, in a

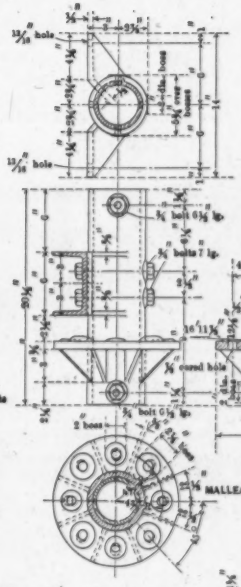
C_6 TRUSS RODS

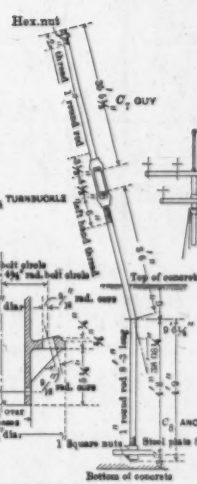


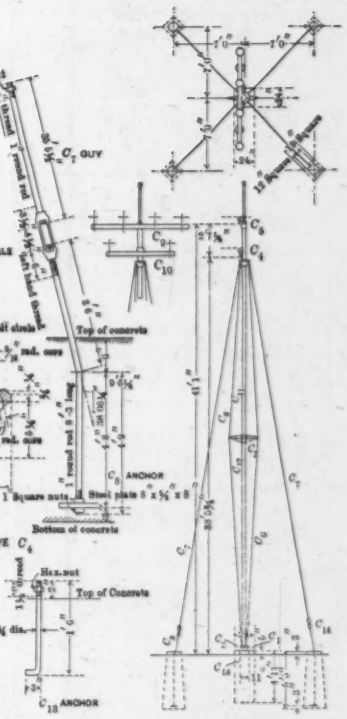


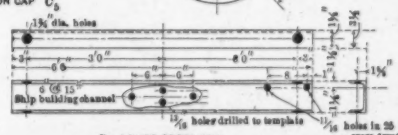


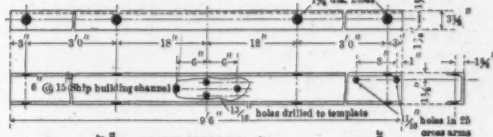
Note:-Holes for ¾" bolts are to be drilled solid 13/16 dia. through C_4 and C_{11} in same operation except those in the lugs which are to be drilled to template.

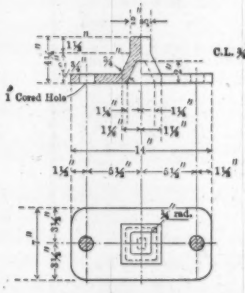


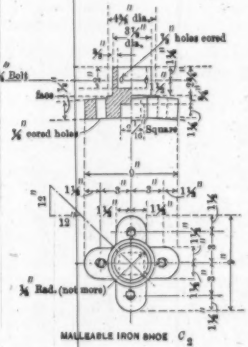


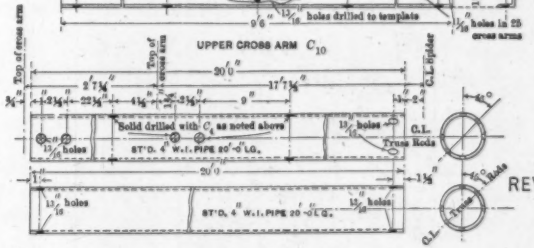












For 1 Pole	Name	Remarks
1	C_1 Foot plate	
1	C_2 Shoe	
1	C_3 Spider	
1	C_4 Sleeve	
1	C_5 Cap	
4	C_6 Truss rods	
4	C_7 Guy rods	
4	C_8 Anchors	
1	C_9 Cross arm	
1	C_{10} " "	
1	C_{11} Pipe	
1	C_{12} "	
2	C_{13} Anchor bolts	
4	C_{14} Turnbuckles	
4	Bolts (Cross arms)	⅝" x 2" Hex. head and nut.
4	" (Cross arms)	¾" x 7" " " "
2	" (Shoe and Spider)	¾" x 5½" " " "
3	" (Sleeve and Spider)	¾" x 6¼" " " "

REVISED PLAN AND DETAILS OF STANDARD POLE FOR NUMBER 2 TRANSMISSION LINE TO BUFFALO.
CANADIAN NIAGARA POWER COMPANY.

locality less favorable than usual, have shown that the value of the anchorage is limited only by the strength of the guy rod. The cross-arms are ship channels; the longer arm is below on the first line, and will be above on the second line. The latter arrangement is not as satisfactory, structurally, but offers certain advantages from the operating standpoint. Malleable castings are used throughout. The pins are malleable on the first line, and will be steel on the second line. The insulators are electrose and the conductors are 500 000 cir. mils, aluminum, with 37 strands. The average spacing of the poles is 300 ft., but, in the writer's opinion, this distance could be increased on tangents to 400 ft., with safety. The pole adopted is economical and durable; it is quickly erected and easily adjusted. It has no thin sections to be destroyed by rust, it requires no field riveting, and but little bolting. The parts could readily be galvanized, but it has not been thought necessary. Its limiting feature is the necessity for good anchorage.

Four reinforced concrete poles of unusually heavy construction are used in the Village of Chippawa, where there was not sufficient space for the standard poles; and steel structures of special construction were used at railroad crossings.

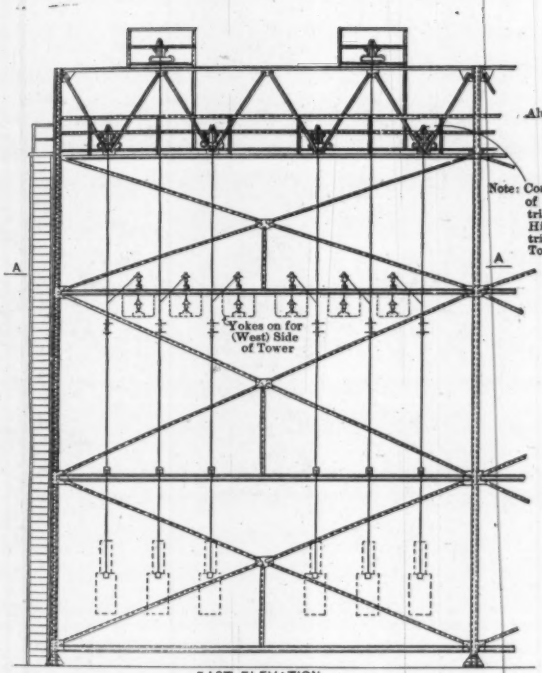
The building of transmission lines with a capacity of 50 000 h. p. across the Niagara River at Buffalo was an enterprise fraught with features both difficult and dangerous. The river at the point of crossing is a deep and rapid stream 1 650 ft. wide, through which passes all the commerce of the Great Lakes with Tonawanda—the largest lumber market in the country—as well as that to various docks in Buffalo. The cables also cross Black Rock Harbor, the Erie Canal, and the tracks of the New York Central and Hudson River Railroad. The Governments of both Canada and the United States required a minimum clearance above the surface of the river of 130 ft. The transmission lines had to pass through or over the Village of Fort Erie, Ontario, where high-voltage lines near the surface of the ground would have been objectionable. A submarine crossing would have been not only expensive in first cost and in renewals, but would have presented many difficulties of construction and maintenance, the bottom of the river being of rock and the terminal-house being about 70 ft. above the river-bed.

An aerial crossing having been decided upon, and numerous diffi-

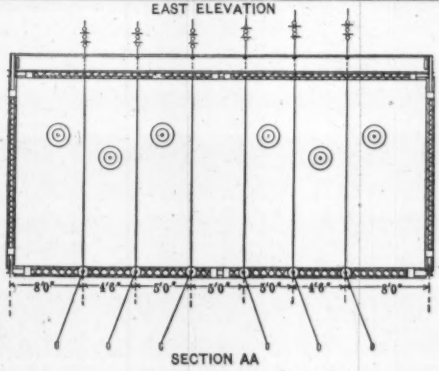
culties respecting rights of way having been successfully overcome, it was decided to carry the conductors upon three towers: One on Bertie Hill, west of the settled portion of Fort Erie, one at the river's edge, and a third adjacent to the terminal-house in Buffalo. The towers thus located have heights of 61 ft., 202 ft. 9 in., and 150 ft. 9 in., respectively. The tops of the higher towers are practically at the same level, while the top of the Bertie Hill tower is 107 ft. below that of the high tower. The span over Fort Erie was fixed at 1 667.57 ft. and that over the river at 2 192.64 ft.

Greater spans have been used elsewhere on transmission lines, notably at the Straits of Carquinez, yet it is believed that the combination of spans of this magnitude, with the large amount of current to be carried, had never before been attempted. Steel, copper, and aluminum, the only materials then commercially available, were carefully considered as conductors. Steel would have been most easily erected, but its conductivity was too low; copper was rejected because, owing to its great weight, the height and cost of the towers would have been greatly increased, and the stability of the foundations of the Bertie Hill tower might have been imperiled. Aluminum was selected because of the more satisfactory relation between its weight, tensile strength, and conductivity. To obtain the greatest strength for a cross-section of 500 000 cir. mils, a 61-strand cable, made with concentric lay, was used, on the recommendation of the manufacturer. The form of lay adopted led to many difficulties which will be referred to later.

It was evident that, with conductors fixed at the ends of the span, if the minimum clearance above the river was to be preserved in summer, the towers adjacent to the river must be about 40 ft. higher than would be necessary if, by some other arrangement, the lowest point of the catenary could be maintained always at the same level; therefore, the following device was used: The conductors were fixed rigidly at the high tower on the Canadian shore, and at the American and Bertie Hill towers they pass over sheaves and thence downward to counterweights which, with the springs above them, weigh 4 400 lb., this weight being calculated to keep the lowest point of the conductors at the proper clearance line. As the temperature decreases or the wind velocity increases, the weights rise, but a constant stress in the cables is assured at all times, thus enabling them to be operated under

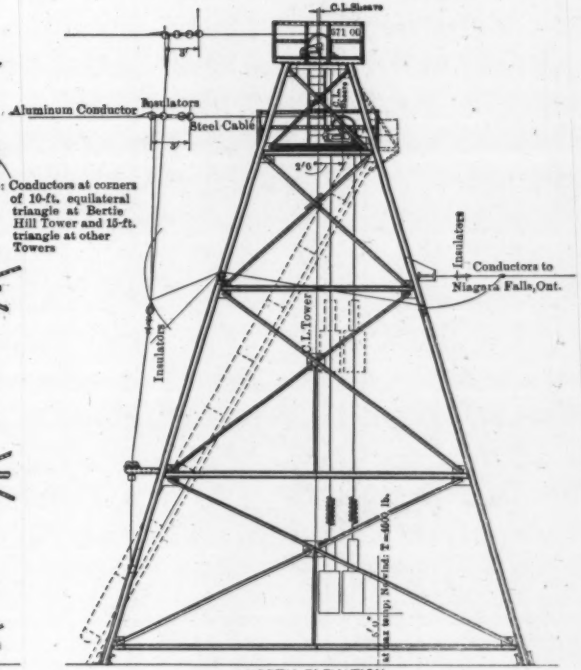


EAST ELEVATION



SECTION AA

Note: Conductors at corners of 10-ft. equilateral triangle at Bertie Hill Tower and 15-ft. triangle at other Towers



NORTH ELEVATION

Cable lengths are calculated on the center line distance between towers = 1669 ft., assuming the towers to be parallel

SECTION AND ELEVATION OF BERTIE HILL TOWER, AT FORT ERIE, ONT.

CANADIAN NIAGARA POWER COMPANY

maximum allowable stress. Plate XXXV shows the arrangement at the Bertie Hill tower, that at the American tower being similar. It will be seen that two pairs of spool insulators are interposed between each aluminum conductor and the steel cable passing over the sheave and connecting with the springs. The latter were added to absorb shocks, but are of doubtful necessity. The live aluminum drop-cables are attached to the main conductors by a wrapped splice, pass over a spool insulator and thence over insulators to connect with the transmission line conductors, counterweights keeping the drop-cables taut. The connection between the drop-cables and the long-span conductors was originally made with tee-clamps, but it was found that, owing to vibration, the conductors deteriorated at these tee-clamps and the wrapped splice was substituted. Experience shows that tee-clamps are to be avoided at all such connections.

Since Plate XXXV was prepared, bus-bars have been installed on the towers, and switches provided, so that a given pole-line circuit may be connected at will with any long-span circuit. Devices have also been added to prevent the swinging of the weights in the wind.

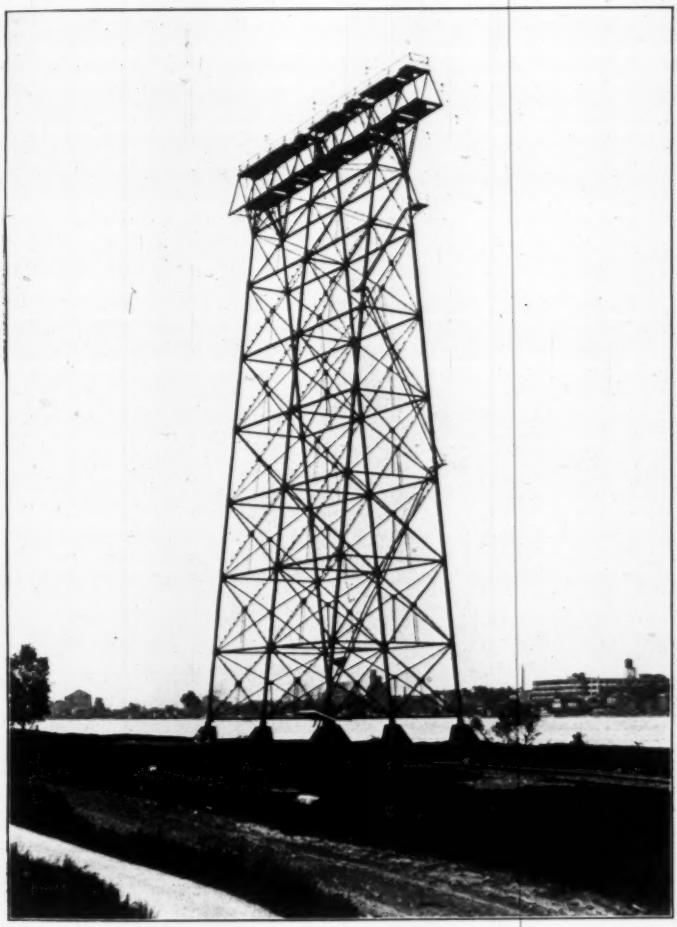
In the original construction the conductors passed continuously from the Bertie Hill tower to the American tower, and were rigidly secured to aluminum saddles on the high tower. However, an unexpected difficulty arose from the vibrations which occurred in the conductors when the air was still or nearly so. These vibrations were similar to those sometimes experienced in telephone or telegraph wires, but were of greater amplitude and violence. Experiments were made to dampen the vibrations, but were unsuccessful, a factor in the failure being the variation in the amplitude. The repeated stresses caused by the vibrations resulted in the breakage of strands of the conductors where they were secured to the saddles. The difficulty was finally overcome by substituting galvanized chain for about 13 ft. of conductor on each side of the saddle. The aluminum conductor passes around an aluminum sheave and returns on itself with a wrapped splice, while the chain connects with a shackle fastened to the axle of the sheave, the current being carried around the chain by an aluminum jumper cable secured to the aluminum sheaves. No trouble has been experienced since these devices have been installed.

The installation of the conductors and the various devices connected therewith, although simple in theory, proved difficult in practice,

and gave rise to many complications which only experience and patience could overcome. The aluminum conductors proved very troublesome. The aluminum was so soft that it had to be guarded from every abrasion; it could not be passed under stress over snatch-blocks; it unstranded readily; and yet it had to go out in perfect condition, as it could not be inspected after erection, and had to operate at a high tensile stress. The rope lay would have been far easier to handle, but the manufacturers thought that a given strand might cut into the adjoining strands under stress. The method of erection finally used was as follows: Telephone service was established between the three towers, flag signals having proved unsatisfactory. Two unusually large hoisting engines were utilized, one at the American tower and one at Bertie Hill tower, from which all the conductors were drawn. A manila rope was first taken across by a tug, the swift current and the frequent passage of vessels rendering this an operation of great difficulty. The rope was used to draw a steel cable consisting of two pieces and having a length somewhat greater than twice the span. The front drum of the Bertie Hill engine was lagged to form a "nigger-head," about 3 ft. in diameter, and was covered with grease.

The reel of aluminum cable having been placed on a special stand provided with a brake, the end of the cable was passed eight times around the drum and thence over a large wheel to its proper position at the top of the tower. A long wooden clamp was then bolted around it near the end, and this was secured to the end of the steel cable connected with the hoisting engine at the American tower. The steel cable leading from the back drum of the Bertie Hill engine was then passed through the opening for the next cable and secured to the other steel cable near the aluminum conductor. The engine on the American side having started up, the aluminum was allowed to pass off the "nigger-head" while the steel cable unwound from the back drum. Thus the single steel cable on the American engine drew over both the steel and aluminum cables.

It was necessary that the two drums on the Bertie Hill engine and the American engine four-fifths of a mile away should work in unison, for if the cables sagged too much, the masts of vessels would be struck, while, if the aluminum conductor was pulled too taut, it would be broken. When the head of the cables reached the high tower, the rear steel cable was disconnected under stress 200 ft. above the



HIGH TOWER ON TRANSMISSION LINES.

ground and carried through the lattice work of the tower in the correct position for the next cable and again secured to the leading cable. The return trip was a simple one, but, on the whole, the work involved much anxiety, owing to the high stresses under which the cables were drawn and the serious consequences which might have attended an accident. In future work of a similar nature, the lot of the engineer will doubtless be a happier one, owing to the use of copper-plated steel-wire conductors or other of the recently produced transmission cables.

The conductors are operating successfully, and are daily carrying to Buffalo large amounts of power for the operation of industries and public service utilities. During a recent sleet storm, which practically doubled the weight of the cables, the apparatus operated exactly as designed, and the conductors were not injured, although, if they had not been counterbalanced, injury to them would have been certain.

Fig. 2, Plate XXXII, is a photograph of a portion of the transmission line between Niagara Falls, Ontario, and Fort Erie, and Plate XXXVI is a view of the high tower, erected upon the Canadian shore of the Niagara River, carrying the conductors to the terminal station in Buffalo, N. Y.

DISCUSSION.

Mr. Parker. JOHN C. PARKER, ASSOC. M. AM. SOC. C. E.—This paper gives a very vivid description of one of the most finished hydro-electric plants. The Society and the profession are to be congratulated that such excellent detailed drawings, photographs, and intimate information are obtainable.

Some slight additional interest attaches to this paper when viewed in conjunction with a paper delivered by P. N. Nunn, M. Am. Soc. C. E.* Mr. Nunn's paper was descriptive of the Ontario Power Company's plant, which is quite closely contiguous to that of the Canadian Power Company. Familiarity with these two plants, and the descriptions, indicate along what diametrically different lines two developments of a similar degree of excellence may be developed. It is interesting to note how, from the fundamental character of the locations of the two plants, entirely different emphasis of detail has been impressed upon the designs. Where one plant is developed with a wheel-pit and tail-tunnel, the other is built in the open, in the river gorge, with but short tail-races and a very long supply flume. One plant uses vertical-shaft turbines and generators with elaborate oil pressure and lubricating systems, the other uses horizontal-shaft units, both members of the unit being contained in the same room and with but a rudimentary lubricating system. One plant represents a highly concentrated development, the other a geographically extensive layout. In one case protection from ice is less nearly automatic than in the other, but, at the same time, has involved materially simpler intake works. In one case control of the operation and of the electric circuits is entirely in the power-house, the transformer station being quite subordinate; in the other the transforming station becomes the seat of control. It will be interesting, as time advances, to note the operation of these two most excellent plants with reference to the numerous points of dissimilarity in the detail.

In discussing the dimensions of the draft-tubes, the author, referring to the high discharge velocity of 21 ft. per sec., suggests the utilization of this velocity in imparting to the discharge water a part of the velocity required in the tunnel because of the angle made by the draft-tubes with the tail-race. The speaker would like to inquire whether, by gradual enlargement of the draft-tube just before it enters the tail-race, and especially by making the enlargement on the down-stream side, much of the shock would not be obviated? There are doubtless adequate reasons why this has not been done, but it seems that no great portion of the velocity head would be recovered in the impact.

* At the Annual Convention of the American Institute of Electrical Engineers at Asheville in 1905.

Mr. Parker.

The formation of the inlet and outlet casings of the turbine are of much interest. It seems rather surprising that in such large units the manufacturers should have designed a concentric casing in which flow to and from the runner must, of necessity, be clockwise in some parts of the casing and counter-clockwise in others. This must involve either additional work by the diffusion vanes and special construction of the various vanes around the periphery, or considerable shock in the inlet and discharge, and would seem to involve necessarily the localization of the flow into the runner. As contrasted with this form of casing, it is interesting to note the vortical type sometimes used, both in turbines and in the inverted form of the turbine—the centrifugal pump. Unquestionably, in view of the vast and uniformly creditable experience of the manufacturers, these details have been provided for, but it would be interesting to know what means have accomplished these ends, or whether they have been sacrificed to other and more important desiderata.

It would be interesting, also, to inquire what provisions or considerations of design have been brought to bear on the matter of acceleration and retardation in the discharge tunnel. Ordinarily, a very considerable reactive effect on the governors might be expected, when, owing to the sudden closing of the gates, the tail-race discharge, under its momentum, tends to lower the water level in the race, increasing the head and thereby offsetting in part the operation of the governor; similarly, with a sudden increase of load, there would be a piling up of water in the tail-race. With designs of a certain character this might be expected to cause racing or to augment the duty required of the governor. The throttling gate at the lower end of the tail-race in this plant, of course, tends to minimize such difficulties on the closure of the wheel gates, which is the more severe condition, but, on the other hand, under the less severe condition of opening, would augment any such tendency. It seems quite probable that in this particular case the balance of the effect from the throttling would be favorable rather than otherwise.

The transmission structures are novel and striking in many details. The construction would seem to be a remarkably simple one, easy of erection and maintenance. One detail in particular seems to be most excellent, and that is the comparative ease with which the cross-arms can swivel on the top pipe, relieving the structure of an otherwise unsupportable strain, longitudinally of the line, in case of breakage of one cable. It is interesting to notice also that provision has apparently been made for carrying an overhead grounded cable for lightning protection. It would be interesting to know whether this has been installed, and, if so, what conclusions the power company has arrived at with reference to the value of such protection.

As to galvanized and painted structures, the speaker believes that

Mr. Parker. the balance of favor is with the former, especially where two circuits are carried on one line of poles, rendering repainting without interruption of service a difficult matter. Some time ago, in preparing figures with reference to this point, the speaker found that on a certain structure, which it would cost $4 to paint, galvanizing could be done for only $11. The experience of windmill manufacturers has been that hot galvanizing, properly applied, will easily last practically intact for 20 years, so that the cost of repainting during this period would probably exceed the initial cost of galvanizing.

With reference to the span, it has been found quite feasible on several transmission lines to go to 550 ft., and this span will doubtless be exceeded with the advent of higher voltages and more costly insulators, especially where the latter are made of the underhung type. On the other hand, of course, an upper limit must speedily be reached, especially with aluminum cables, because the sag of the latter, markedly in the smaller sizes, rapidly increases with the span, and the tower cost goes up even more rapidly as the height is increased. In a line recently placed by the speaker, using aluminum cable of 214 000 cir. mils, it was found necessary to use a sag of 24.5 ft. when stringing at summer temperatures to a span of 550 ft. This involved a tower 56 ft. in height and necessarily a fairly heavy construction, as the width of the right of way and of the permissible tower base was restricted.

The manhole and duct construction shown in Fig. 7 is in striking contrast to the ordinary construction adopted by distribution companies, and perhaps would be economically impossible for such purposes. It emphasizes one fact, however, which ordinarily has received all too little consideration, and that is the impossibility of getting rid of the heat produced in the center of a large block of ducts. The speaker believes that as time progresses even the small distribution companies will learn that such grouping is not good.

Much speculation has been indulged in with reference to the swinging of transmission cables as a result of gusts of wind. Experience has proven that on large spans supported on towers the cables swing synchronously, owing probably to the forced vibration produced by the reaction of one cable on the other through the more or less elastic tower. The Niagara River crossing, however, presents a modification of the ordinary condition in that the cables are not rigidly attached to the towers, and hence are not likely to communicate to the towers the elastic stress produced by the wind. In fact, the whole philosophy of the counterbalance weight is to keep this stress—or the vertical dip of the cable—constant. It would be interesting to know whether, in this crossing, the wind strains have been felt uniformly by all the cables, so as to permit synchronous swinging and hence to eliminate the danger of lines coming into contact.

WILLIAM J. BOUCHER, ASSOC. M. AM. SOC. C. E.—The author is to be congratulated on this very interesting and valuable paper. The Canadian plant appears to resemble that on the New York side in many particulars, but it differs from the latter in so many ways that Mr. Van Cleve's description forms a very desirable addition to the literature on hydro-electric plants. Mr. Boucher.

Mention is made of the market for the electric current, and, in addition to its uses in comparatively near localities, it is now transmitted as far east as Syracuse, a distance of 150 miles, where it operates the entire street-railway system. Current is also supplied to about half of the electrified portion of the West Shore Railroad operating between Syracuse and Utica, which makes the total distance of transmission nearly 175 miles.

The "creeping" or "moving" of the walls of the wheel-pit is a very curious phenomenon and, if Mr. Van Cleve is prepared to give further information, it would be interesting to learn if a satisfactory cause has been assigned. How much have the walls moved since the completion of the excavation? Is it expected that the creeping will continue, and if so, at what rate; and did similar creeping take place at the plant on the New York side?

With reference to the method of excavating by channeling the sides, was the central core afterward blasted out? Figures of cost of excavation by this method, if the author is at liberty to give them, would be instructive.

A. H. VAN CLEVE, M. AM. SOC. C. E. (by letter).—Mr. Parker refers to the contrasting designs in the plants of the Canadian Niagara Power Company and The Ontario Power Company. It may be noted that franchise requirements dictated many of the governing features of these developments, and each plant as now constructed is the result of ideas which were originally very different from those embodied in the completed design. In the writer's opinion, a masonry tail-race 2 200 ft. long has many points of advantage over a steel penstock 6 000 ft. in length, but, on the other hand, an intake located above the line of rapids enables the ice difficulties to be met more satisfactorily than with an entrance canal located in their midst. The operating records of these two plants will certainly be interesting to those to whom shall be entrusted the designs of developments similarly situated. Mr. Van Cleve.

The writer does not wish to be understood as advocating a velocity in draft-tubes as high as 21 ft. per sec., yet, under usual conditions, water discharged from the draft-tubes in the plant under consideration undoubtedly has a velocity in a useful direction toward the outlet of the wheel-pit, for, as the draft-tubes discharge at an angle of 45° with the longitudinal axis of the wheel-pit, a component theoretically equal to $V\sqrt{\frac{1}{2}}$ is parallel thereto. If only one wheel were in operation and the tail-race control gate held a material depth of water in

Mr. Van Cleve. the pit, of course the velocity would be used up in impact, but under normal conditions, with nearly all the wheels running, the discharge velocity will reduce the amount by which the water must bank up in the wheel-pit to obtain its tunnel velocity. It would have been extremely difficult to increase the size of side-wall draft-tubes. The most practical way to decrease the velocity in the draft-tubes would have been by the introduction of a third draft-tube discharging directly into the tail-race.

The advantages of the spiral, or involute, wheel-case in increasing the efficiency of the apparatus cannot be gainsaid, but an inspection of the tabulation which segregates the several losses of efficiency in the 10 000-h. p. units shows that the loss in the existing wheel-case is not excessive, and it may be readily computed that the gain in efficiency will not exceed 1% by the use of a spiral case. In designing what was then the largest hydraulic unit in the world, it is perhaps natural that the simplest form of wheel-case should be chosen, especially as it would not be practical to make a spiral case of such a size as to include both wheels. The advance of the art has enabled the engineers of the Canadian Niagara Power Company to evolve a design for additional units which will provide for two wheels on the same shaft, each in a separate spiral case. Owing to the deflector on the shaft, the water moves smoothly through the draft-chest, in the design described in the paper, and but little opportunity for improvement exists here.

If, from any cause, large increments of load are suddenly thrown off the plant, the level of the water in the tail-race will fall; and if, under some most unusual condition, a large increase in load should be instantly added, the level of the water in the tail-race of course would rise, the effect of both changes in condition being intensified by the inertia of the water flowing in the tunnel. Undoubtedly the effect of such inertia is to add to the duty required of the governors, but this would appear to be a theoretical rather than a practical consideration, as the governors installed completely close the valves on the wheels, from a position of wide-open, in 2½ sec., and the effect of the inertia is not appreciably exerted in this time, as the performance of the governor indicates. No difficulty from "racing" has been experienced.

While a certain amount of flexibility is provided by the design of the cross-arm and pole used on the transmission line, this is not necessary to relieve the structure of an "otherwise insupportable strain," as the entire pole is designed so as to withstand safely the breakage of a conductor.

A guard wire was used on the second transmission line to Buffalo, but, owing to the fact that no severe lightning storms have occurred since its installation, no opinion may be formed as to its protective value. It can only be said that the line has not been affected by lightning phenomena up to the present time.

Mr. Van Cleve.

As the materials for the poles illustrated in the paper were of necessity obtained from various sources and fabricated at the company's shop, to which no galvanizing baths were convenient, it would have been excessively expensive to use the galvanizing process on the several parts of the poles. No such necessity existed as in the case of the usual angle-iron pole with its thin sections, and doubtless the carefully applied paint will last many years.

The 500 000-cir. mil conductors were so strong as to have a stress per conductor of 1 000 lb. at 60° Fahr., with no wind, corresponding to a sag of 5.2 ft. on a span of 300 ft. This will result in a stress per conductor of 2 400 lb. at 30° Fahr., with wind having an indicated velocity of 100 miles per hour.

It was realized when the aerial crossing of the Niagara River was first contemplated that the success of the undertaking was largely dependent upon the synchronous swinging of the cables, and it was therefore with the keenest interest that the writer watched the first two cables swinging in the wind, although preliminary experiments had demonstrated the synchronism of long spans. Since then, nine cables have been observed under every possible condition, including a storm when the wind attained a velocity of 80 miles per hour. Uniformly, the movement of the cables has been synchronous. It is true that sometimes the windward cable will commence to move first when struck with a sudden gust, but such deviation from true synchronism is inconsequent.

As Mr. Boucher remarks, power is now transmitted from Niagara Falls to Syracuse, an interesting fact illustrating the progress of the art since those early days of the Nineties when the transmission to Buffalo was a problem so difficult as to enlist in its solution some of the keenest minds in this and other lands. The Canadian Niagara Power Company is fortunate in finding a market for its power in localities near at hand and thus avoiding the difficulties of operation still more or less in evidence in long-distance transmission.

When the inward movement of the walls of wheel-pit No. 1 of The Niagara Falls Power Company first attracted attention in 1897 the theories advanced in attempted explanation of this phenomenon were almost as numerous as the observers. Even the moon was held to be guilty. But as time has passed and an opportunity has been afforded to study the action still further in wheel-pit No. 2 of the above-mentioned company and in the wheel-pit of the Canadian Niagara Power Company, the simple explanation long held by the writer appears to be the most plausible, namely, that when a long deep gash is cut in the crust of the earth the shrinkage stresses, present at all times in that crust, are relieved by the inward movement of the rock forming the sides of the opening. When and as soon as these stresses are thus relieved, the movement practically ceases except in so far as changes of temperature may cause slight inward and outward movements, the

Mr. Van Cleve.

maximum width of the pits being attained in May and the minimum width in November. The movements of the sixteen points in the wheel-pit of The Canadian Niagara Power Company have been measured at frequent intervals for 3½ years, but the amount of the seasonal movements varies from point to point so that no general law may be laid down as to the extent of the movement in a given period of time. In general, it may be said that points near the thrust-deck have a smaller range of movement than those near the rack-deck. There is every reason to suppose that slight seasonal movements will continue to take place in the wheel-pit of the Canadian Niagara Power Company as they have in the pits of the allied company in Niagara Falls, N. Y.

After the sides of the wheel-pit were channeled to a depth of 6 ft. at a given place a row of holes was drilled across the pit and the face of the bench was blasted off down to the bottom of the channel cuts. Thus the bench was carried back from end to end of the pit, the channelers being always in advance of the drills. The average cut of a channeler in the limestone through which the pit was excavated was about 70 sq. ft. per day, the day consisting of two shifts of 10 hours each.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1098

FORESTS AND RESERVOIRS IN THEIR RELATION TO STREAM FLOW, WITH PARTICULAR REFERENCE TO NAVIGABLE RIVERS.*

By H. M. Chittenden,† M. Am. Soc. C. E.

With Discussion by Messrs. F. Collingwood, Thomas P. Roberts, Stephen Child, L. J. Le Conte, F. B. Maltby, J. Francis Le Baron, Edward P. North, A. Miller Todd, William W. Harts, George Otis Smith, George F. Swain, W. H. Leffingwell and A. M. Strong, Bailey Willis, M. O. Leighton, W. D. Pickett, Robert E. McMath, H. F. Labelle, Emil Kuichling, Robert Fletcher, J. P. Snow, Clarence T. Johnston, Gifford Pinchot, and H. M. Chittenden.

The following paper is presented at this time with the purpose of eliciting from the Society membership the results of observation and experience touching the important matters of which it treats. They are vital features of one of the chief living questions before the public to-day, and an expression of views by men accustomed to look at things from a practical standpoint cannot fail to be of great value to our legislators upon whom the ultimate responsibility for action must rest.

While the writer's views traverse, to some extent, currently accepted theories, they are based upon long observation and study, and are what seem to be unavoidable conclusions therefrom; but he is com-

*Presented at the meeting of November 4th, 1908.
†Lieut.-Col., Corps of Engineers, U. S. Army.

mitted to no theory, as such, and his mind is entirely open to conviction upon any point in which his opinions may be shown to be erroneous. His sympathies are wholly on the side of the present movement for the conservation of our natural resources, and, so far as this paper takes issue with certain tendencies of that movement, it is only for the purpose of inquiring whether such tendencies are not really inimical to the cause to which they pertain.

With this preliminary statement, the writer will take up the first part of his paper, viz., the influence of forests upon stream flow.

Forests and Stream Flow.

The commonly accepted opinion is that forests have a beneficial influence on stream flow:

(1) By storing the waters from rain and melting snow in the bed of humus that develops under forest cover, preventing their rapid rush to the streams and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off.

(2) By retarding the snow-melting in the spring and prolonging the run-off from that source.

(3) By increasing precipitation.

(4) By preventing erosion of the soil on steep slopes and thereby protecting watercourses, canals, reservoirs and similar works from accumulations of silt.

There are many subsidiary influences, but, broadly stated, the above propositions cover the ground. They were first given general currency nearly forty years ago through the writings of Sir Gustav Wex, Chief Engineer on the Improvement of the Danube, whose treatise was translated into English by the late General Weitzel, of the Corps of Engineers. Wex's theories were stoutly resisted at the time by many European engineers, and still find only a limited acceptance in the profession;* though in the popular mind they have gained ground and in the United States are now accepted practically without question.

To establish by definite proof the truth or falsity of these propositions is an extremely difficult task. One would not think so, indeed, to judge from the cheerful confidence with which the popular thought accepts them; but it is nevertheless so. The elements of the problem are so many and conflicting, the necessary evidence is so hard to get,

*Almost simultaneously with the publication of Wex's treatise, a similar work was published in France by M. F. Vallée taking exactly the opposite view of the question.

and comparative records are of such recent date, that precise demonstration is scarcely possible. The popular belief is based upon a fact and an assumption forming together a basis for a conclusion. The fact is that forests in the eastern portion of the United States have disappeared to a large extent within the past century. The assumption is that floods and low waters in the same region are more frequent and severe than before the forests were cleared away. The conclusion is that these assumed conditions must be due to the disappearance of the forests. *Post hoc, ergo propter hoc* is the argumentative process relied upon, and little effort is made to consider whether there may not be some other and more satisfactory explanation. The writer will attempt to analyze the problem from a theoretical standpoint and will then cite existing records so far as these are sufficiently long-continued to be worth anything. He will consider, first, the effect of the forests where stream flow results from rain alone, and, next, where it results in part from melting snow.

Effect of Forests upon the Run-Off from Rainfall.—The first of the above propositions—the retentive action of the forest bed—may be accepted at once as strictly true for average conditions. It is not true for extreme conditions—great floods and excessively low waters—the conditions that determine the character and cost of river control. Consider an inclined-plane surface, practically impervious to water, with a layer of sand covering some small portion of it, and let a uniform spray of water be applied to the entire surface. Assume that the temperature and rate of evaporation are relatively low. As soon as the spray begins, water commences to flow from the uncovered surface, but not for a time from that covered by the sand. After a while it begins to trickle from the sand, increasing in volume until the sand is thoroughly saturated, after which it flows off in as great quantity per unit area as from the uncovered portion. If the spray is stopped, the water immediately ceases to flow from the uncovered area, but continues in diminishing quantity from the covered area until it finally ceases altogether; but not all the water that fell on this area has run away. The sand has retained some portion of it and given it off in evaporation, so that the total run-off per unit area is somewhat less than on the uncovered portion. If the shower be long-continued and the rate of evaporation very low, the difference of total run-off per unit area from the two surfaces will be very slight.

Suppose now that the temperature and rate of evaporation are high

and that the spray works intermittently. If the showers are small in volume and the intervals between them long, the sand may retain nearly or quite all of the individual showers and give them off in evaporation, so that there will be no run-off whatever.

Between these two extreme conditions, the covered area will exert a greater or smaller regulative effect upon the run-off. The retentive power of the sand will be less as the slope of the surface upon which it rests increases, or it will be greatest when the surface is nearly horizontal and least when it is nearly vertical.*

Now in Nature this ideal illustration is never fully exemplified in the cleared land and the forest. There is nearly everywhere a marked retentive capacity in the bare soil. In newly plowed ground it is probably greater than in the forest. Moreover, certain crops, like heavy grass or grain, obstruct the flow of water almost as much as the forest cover. On the other hand, the furrows of cultivated fields, drainage ditches, roads and, particularly, the pavements and roofs of towns, greatly accelerate the run-off; so that, while the full contrast of the ideal example does not exist in Nature, the principle of the illustration applies perfectly. That is, there are times when the percentage of retention in the forest bed is 0, and there are other times when it is 100; or, there are times when so much water comes that the forest bed can hold none of it and there are times when so little comes that it holds it all. Between these extremes there are periods when it holds more or less and gives up less or more and exercises a

*Since the above was written the writer has noticed, in the report of the hearing on House Resolution 208 before the Committee on the Judiciary, that Gifford Pinchot, Assoc. Am. Soc. C. E., Chief of the Forest Service, used an illustration very similar to that given above, except that he failed to carry it to its logical conclusion. Addressing the Committee, February 27th, 1908, he said: "I have in my hand here a photograph of a denuded hillside. After the forest has been removed rain falls on that hillside and runs off rapidly, as the water I drop upon the photograph does now, and disappears instantly (illustrating). If, on the other hand, I place a forest cover on the hillside, that is exactly analogous in texture and effect with this piece of blotting paper, and drop the water slowly upon it, we would find that, instead of running off slowly at the bottom, the water is held (illustrating with blotting paper). Part of it runs off, but, as soon as the absorbent quality of the paper or the forest floor has time to take effect, the water is kept and drips gradually for a considerable length of time off the hill into the stream. This is an exact illustration of the way in which the forest controls the stream flow on that hillside."

Mr. Pinchot should have completed his illustration. He should have continued to sprinkle the paper long enough and heavily enough to have saturated it completely in order to show that the water would then flow from the paper as rapidly as from the uncovered area; and he should then have explained that this condition represents what always happens in the forest in times of great flood. Then he should have sprinkled the paper intermittently in small quantities, and at such long intervals that the warm air of the room would evaporate all of the absorbed water, and that none whatever would flow away. He should then have explained that this condition represents what always takes place in the forest in times of great drought.

corresponding influence upon the run-off. There is another important condition not exemplified in the illustration, and that is that the forest areas are scattered everywhere, the ground has an infinite variety of slope, the showers never fall uniformly over an entire water-shed, and the final result in the total run-off is the summation of thousands of tributary results.

It is true, therefore, as popularly understood, that, in periods of ordinary rainfall with sufficient intervals for the forest bed to dry out somewhat, forests do exert a regulative effect upon run-off. They modify freshets and torrents, and prolong the run-off after storms have passed, and thus realize in greater or less perfection the commonly accepted theory.

This result utterly fails, however, in those periods of long-continued, widespread and heavy precipitation, which alone cause great floods in the large rivers. At such times the forest bed becomes completely saturated, its storage capacity exhausted, and it has no more power to restrain floods than the open country itself. Moreover, the fact that the forest bed has retained a portion of earlier rainfall and is yielding it up later to the streams, produces a condition that may be worse than it would be in a country cleared of forests. Really great floods in large rivers are always, as is well known, the result of combinations from the various tributaries. It is when the floods from these tributaries arrive simultaneously at a common point that calamitous results follow. Any cause which facilitates such combinations is, therefore, a source of danger. Now, unquestionably, in a heavily wooded water-shed, forests do have a tendency in this direction. When a period of heavy storms occurs, spreading over a great area, continually increasing in intensity, the forests, by retaining some portion of the earlier showers and paying them out afterward, do produce a general high condition of the river which may greatly aggravate a sudden flood arising later from some portion of the water-shed. That the forest does promote tributary combinations, there would seem to be no question, and that it may therefore aggravate flood conditions necessarily follows. It is not contended that this increase is ever very great, but it is contended that forests never diminish great floods and that they probably do increase them somewhat. The forests are virtually automatic reservoirs, not subject to intelligent control, and act just as the system of reservoirs once proposed by the French Government

for the control of floods in the River Rhone would have acted, if built. These reservoirs were to have open outlets, not capable of being closed, which were intended to restrain only a portion of the flow. A careful study of their operation in certain recorded floods showed that they would actually have produced combinations more dangerous than would have occurred without them.

Consider now periods of extreme drought, and grant that, as a general rule, springs and little streams dry up more completely than when forests covered the country, although this difference is very greatly exaggerated in the popular mind.* At first thought one would conclude that, since the springs and streams make up the rivers, these also ought now to show a smaller low-water flow than formerly. This, however, is not the case. The difference between the former low-water flow of a spring or rivulet and what it is now is relatively an insignificant quantity. Most of such water sources yield but a small fraction of a cubic foot per second. Whether these small quantities are a trifle more or less cuts very little figure in the aggregate; and so it counts but little in the flow of a great river whether some of its extreme sources lose a portion of a volume that is already inappreciable. When the summer showers come, however, there is a marked difference. At such times the forests not only hold the water back—they often swallow it completely. Small showers that make a perceptible run-off in the open are often practically all absorbed in the leaves of the trees. Heavier showers, that make freshets in the open, are largely absorbed in the leaves and forest bed and pass off in evaporation; so that, contrary to the general view, the evaporation from the forest is greater at such times than in the open country, and the run-off from summer precipitation is less. A single shower may produce a sufficiently greater run-off in a deforested area to more than offset the diminished low-water flow for several weeks.† Now on most of the smaller streams quantity of flow is a more important matter than

*The term "as a general rule" is used, for it is by no means absolute. In particular the drainage of low swamp lands leads off into the streams, in dry weather, waters that formerly remained or passed off in evaporation, and in such cases even the low-water flow is greater than it used to be. In 1895 the writer saw an example of this on the Scioto River near the outlet of the great Scioto swamp which had recently been drained. A small mill was able to operate during the low-water season more regularly than formerly. Tile drainage, now so widely used, has the same tendency.

†So far as the writer is aware, Colonel T. P. Roberts, of Pittsburg, Pa., was the first to call attention to this characteristic of stream flow.

natural uniformity of flow, particularly in the summer time. The day of the small mill, which was so dependent upon such uniformity, is past. The modern water-power invariably seeks uniformity by artificial regulation, and the ups and downs of its sources of supply are abolished in its storage. Therefore it does not matter nearly as much that the run-off of the small streams be uniform as that it yield a good flow of water; and if forests diminish the total low-water supply, this fact more than offsets the gain in uniformity. Likewise, the great rivers swallow up and equalize the small irregularities of their head-waters and actually experience a somewhat larger low-water flow than if their water-sheds were still thickly forested. Thus, while forests may decrease somewhat the extreme range between maximum and minimum run-off on very small water-sheds, they do not do so on great ones, which are combinations of very small ones. At the same time it seems certain that forests decrease somewhat the total run-off from water-sheds small or great.*

Influence of Forests upon Snow-Melting.—The second proposition —that forests have a beneficial effect upon the run-off from snow-melting—is quite as firmly fixed in the popular belief as that just considered, but has even less foundation in fact. It is a relation that can be definitely traced, and it can be demonstrated that the effect of forests upon the run-off from snow is invariably to increase its intensity. This results from two causes, one affecting the falling of the snow and the other its melting.

In the first place, forests break the wind, prevent the formation of drifts, and distribute the snow in an even blanket over the ground. In the open country, the snow is largely heaped into drifts, their size depending upon the configuration of the ground, the presence of wind breaks, and the prevalence and force of the wind. These drifts form admirable reservoirs, and in the high mountains are the most perfect known. Forests prevent their formation entirely.

The period of snow-melting begins in the open country much earlier than in the forests. At first the melting is due mainly to the direct

*This subject was ably discussed by Mr. Raphael Zon, of the Forest Service, Department of Agriculture, in *Transactions*, Am. Soc. C. E., Vol. LIX, pp. 494-495. He states among other things that "the quantity of water available for stream flow from forested water-sheds, all other conditions being equal, is less than from non-forested water-sheds"; that "the forest soil receives least precipitation, next comes meadow land, and lastly tilled land"; that "in the forest, only the upper layer of the soil is moister than in the open, the lower layers being always drier." This discussion is well worth perusal.

action of the sun's rays before there is sufficient warmth in the general atmosphere to produce any effect. The thinly covered areas melt off first and the streams experience a diurnal rise and fall following the warmth of day and the frost of night. Nothing like a flood ever arises from such melting.

Under forest cover this action is interfered with more or less, depending upon the density of the shade. Even after the ground in the open is entirely bare, except under the drifts, the forest areas may still be covered with an unbroken layer of snow. It is generally, though erroneously, considered that this delay is beneficial, by carrying farther into the summer the release of the winter precipitation and giving it more time to soak into the ground; but in fact this benefit does not result. The water from the first melting of the snow blanket does not sink into the ground but into itself. Snow is like a sponge. A panful light will shrink to one-fourth of its volume, or less, before any free water appears. The author has seen an 8-ft. covering of snow dwindle to 2 ft., with the ground beneath it still comparatively dry.

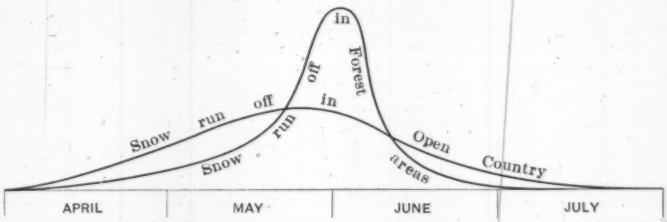
The forest shade thus holds the snow, which gradually becomes saturated from its own melting, until the heat and warm rains of late spring or early summer arrive, the soft air everywhere pervading the forest depths and finding a maximum exposure of surface to the melting influences. A cubic yard of snow which in a great drift might stand 27 ft. deep with a square foot of exposure, may here lie with a depth of 1 ft. and 27 sq. ft. of exposure. The result is that when the final melting begins the whole body of snow disappears very rapidly, rushing from every direction into the streams, swelling them to their limit and often causing disastrous freshets. The active melting lasts but a short time, and there is little opportunity for the water to soak into the ground. The delay in melting, caused by the forest shade, has simply operated to concentrate it into a shorter period and increase the intensity of the resulting freshet. It comes so fast that the greater portion of it cannot be utilized at the time and is lost altogether unless intercepted by reservoirs.

In the open country, on the other hand, the drifts last for weeks after the snow has entirely disappeared from the forest, and continue to yield a supply of water far into the summer. The period of active melting in the open may have lasted four months, that in the forest scarcely as many weeks. Fig. 1 illustrates, in a general way, the

FIG. 1.—SNOW IN FOREST, YELLOWSTONE PARK, JUNE 13TH, 1899. ALTITUDE, 8 200 FT.

FIG. 2.—SNOW-DRIFT, YELLOWSTONE PARK, JUNE 13TH, 1899. ALTITUDE, 7 800 FT

processes just described. These curves apply more particularly to the forests of the Rocky Mountains, where the writer has had exceptional opportunities for studying their action. In the northwest corner of Wyoming and in contiguous portions of the adjoining States, lies an elevated region of probably 20 000 sq. miles, which is the source of nearly all the great river systems of the West. It is a very remarkable region in this respect. Its average altitude is about 7 500 ft., and it is in large part covered with a dense evergreen forest. At the very summit of this elevated region is that singular section now visited annually by thousands of tourists—the Yellowstone Park. The opening of the tourist season in spring occurs just about the time of active snow-melting, and the most onerous and difficult task of those in charge of the road system of the Park is to get the roads into condi-



GRAPHIC ILLUSTRATION OF SNOW MELTING IN FORESTS AND OPEN COUNTRY, ROCKY MOUNTAIN REGION.

FIG. 1.

tion for the first travel. This frequently has to be done while the snow still lies deep on the ground. It was the repeated execution of this task that first drew the writer's attention to the fact that, as a general rule, the floods of this region are forest floods, and that the same conditions of precipitation which force the forest streams out of their banks produce only moderate effects in the open. The traditional "June rise" comes mainly from the mountain forests.

The photographs presented herewith were taken about the middle of June in a year of heavy snowfall and only two days before the tourist season opened. Fig. 1, Plate XXXVII, shows an east and west road through a dense forest of lodge-pole pine at an altitude of 8 200 ft. It shows very effectively the deep, even blanket of snow everywhere covering the ground, except along a narrow strip at the roots of the

trees on the north side of the road, where the sun had access through the opening in the tree-tops caused by the 30-ft. clearing for the roadway. Fig. 2, Plate XXXVII, taken practically at the same time, shows one of the great drifts in the open country, which it was impossible to avoid in locating the road.

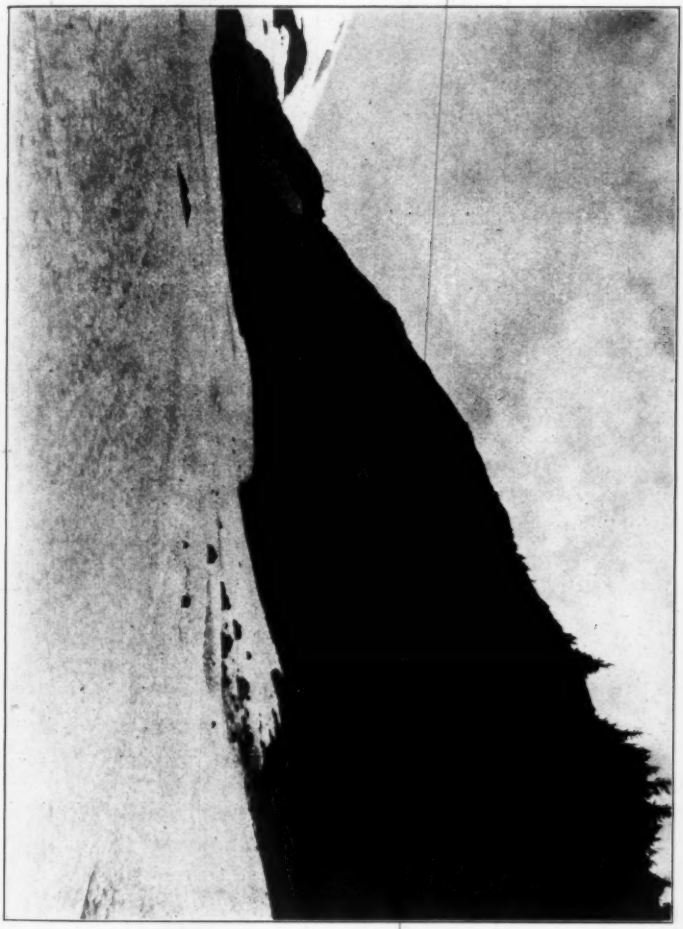
At this time a period of very warm weather had set in, with frequent rains. Severe floods followed which did great injury to the roads and bridges, not only in the mountains, but for a considerable distance below. Within two weeks the snow had practically disappeared in the forests, but in the open country the drifts, like that in the photograph, continued until the middle of July, giving forth a continuous supply of water.

A most illuminating article, and one which every one interested in the subject should read, was published in *Science* for April 10th, 1896. It gives the results of observations in the mountains of Nevada for more than 25 years, during which "extensive tracts of timber" were cut off "to the very ground," and new growths had been well started. It was found that springs, which were active after the land was cleared, dried up when the new forest growth developed; "that the water supply from the mountains is greater and more permanent now than it was before the timber was cut off"; that freshets were no more "frequent or violent than before the trees were cut off," and that "spring floods were less frequent." The greatly increased loss due to evaporation in the forest was pointed out. This results partly from the vast extent of surface on the ground exposed to the air and partly from exposure on the leaves and branches of the trees.

"The foliage on this class of trees being as heavy in winter as in summer, the branches catch an immense amount of the falling snow and hold it up in mid-air for both sun and air to work upon; and only those who have had experience of the absorbing power of the dry mountain air can form any idea of the loss from that source." Moreover, "the trees absorb from the soil quite as much water as would be evaporated by the action of the sun in the absence of the shade."

The writer of that article states that

"the strongest force at work to save our rivers is the drifting winds which heap up the snow in great banks; and in this the trees are a constant obstacle." He declares that "close observers, after long years of study, have been led to believe that if there is any difference in the



"IN THE BASKET."

flow of streams and the size of springs before and after the trees are cut from above them, the balance is in the favor of the open country."*

In the current literature upon this subject one invariably encounters the same fallacious assumption, that because the forests delay melting their action is therefore beneficial. The fact is entirely overlooked that delay means concentration and greater intensity of run-off, while the open country prolongs the melting and gives a more even distribution. If the true action of forests in this respect, however, is rarely recognized by public writers, it is recognized, though perhaps unconsciously, by those who are benefited by it. The monthly reports of the Weather Bureau in the Rocky Mountain region are instructive reading in this connection. The following are a few extracts from those sent in to the Central Office of the Western Montana district at Helena:

"Where there is no timber to break the force of the winds solid drifts of considerable depth have collected." * * * "The snowfall has been very light and the drifts are not large or solid enough to furnish an adequate flow of water in the streams." * * * "In some sections the winter's snowfall has been the lightest for many years, and as there is little likelihood that the later snows will form solid drifts, it is practically certain that the flow of water in most streams will be inadequate for irrigation and mining purposes."

These extracts, which could be multiplied indefinitely, show how well the practical ranchman understands the value of snow-drifts. It has always been a mystery to the writer that writers will persist in statements like the following, which appears in one of the ablest addresses at the recent Conservation Conference in Washington:

"The possibility of irrigation depends largely on the preservation of the forest cover of the mountains, which catches and holds the melting snows, and thus forms the great storage reservoirs of nature."

The forests destroy the reservoirs, and the flow would be more uniform, prolonged and plentiful, if they were not there.

It will doubtless be urged that while the foregoing conclusions may hold for an elevated and densely wooded region, they will not hold

*The writer recalls only a single other writer who has set forth this matter in accordance with the facts, and that was an anonymous correspondent in a recent issue of the *Pacific Sportsman*. His view of the case is summarized in rather terse language as follows: "Trees in the mountains make floods in the spring." * * * "Snow in the timber melts too fast. The timber keeps it from drifting." * * * "The agency which maintains the river is the snow in the huge drifts." * * * "That (the drift) is your reservoir that feeds the living streams of summer time." * * * "The timber has nothing to do with the water supply but is a result of the water supply."

for a lower altitude, warmer climate and different kind of forest. In reply it may be said that, in proportion as the conditions described prevail, they apply everywhere. In deciduous forests where the foliage is absent during seasons of snowfall and melting, the winds have greater play in winter and the sunlight in spring, and there is, of course, less difference between the forests and the open country; but while the difference is less it is not obliterated altogether, and in hilly regions, like the Adirondacks and the White Mountains, it exists in full force. The writer is very familiar with the region of Western New York—having been reared on a farm nearly on the divide between the waters of the Ohio and Lake Erie—a beautifully wooded country, deciduous growths prevailing, and one of the snowiest regions in the United States. While there is less drifting in the open and more in the woods than in high mountains, still it is strictly true that the open-country drifts outlast the forest snows just as the latter outlast the thin snows in the open.

A striking example of the action of forests on snow-melting may be seen in the mountains of the Pacific Coast. Here are the densest forests in the world, the deepest beds of humus, and the most perfect reservoir effect so long as it is in action. Yet in this very region, particularly around Puget Sound, are to be found some of the most torrential streams in the country. This fact is largely due to the distribution of snowfall caused by the forests. Conditions like the following are constantly developing. Heavy snow storms sweep over the forest-covered mountains. The snow cannot drift, for the dense woods break the wind. A great deal of it does not reach the ground at all, but hangs on the branches and undergrowth all the way from the highest tree tops down. This covering is often so dense as to prevent cruising operations altogether, because the cruisers cannot see the timber through the impenetrable screen of snow. Of an 18-in. fall, perhaps 12 in. is on the trees and the rest spread evenly on the ground. To show what now happens, let an illustration be drawn from the opposite process of drying clothes. When the housewife has finished her washing and wishes to dry the clothes, she does not set them out in a basket, where it would take weeks for them to dry, but spreads them upon the ground or hangs them on a line, so that the sun and air can reach them on all sides. So these forests increase, by a thousand-fold, the exposed area of the snow over what it would be if heaped in Nature's clothes

"On the Line."

baskets (the great drifts), and give it the maximum possible exposure to the melting influences whenever these shall arrive. As a general rule, these snow storms are followed by warm southerly winds and rains—the rains frequently heavy in themselves—and rain and snow join hands, two storms in one, and rush down to the ocean in tremendous freshets and floods. The Skagit River, the largest in Washington except the Columbia, and a very considerable stream, has been known to rise 1 ft. per hour for 16 hours, and this where the stream has a fall of 4 ft. to the mile and carries off its floods very rapidly. Fig. 1, Plate XL, taken on another stream with only 480 sq. miles of water-shed above it, shows the terrific power of these streams that come down from the most densely wooded and perfectly protected water-shed in existence. The great flood of 1906 in this section, was a perfect demonstration, not only of the vast intensifying effect of forests upon floods due to snow-melting, but of the utter helplessness of the forest bed, when saturated with long rains, to restrain floods.

The same effect was very manifest in the great flood of 1907 in the valley of the Sacramento River, California. The tributaries on the east side come down from the densely wooded slopes of the Sierras; those on the west side from the bare or sparsely wooded slopes of the Coast Range. If the forest theory be true, these smooth western slopes should send down a greater flow for the same precipitation than the eastern slope. Exactly the reverse seems to have been the case. For the period, March 17th-26th, the precipitation on the Puta Creek water-shed, on the west side (805 sq. miles), averaged 22.7 in. The maximum resulting run-off per second per square mile for one day was 39.1 cu. ft. Directly across the valley, on the Sierra slope, the precipitation on the American River water-shed (2 000 sq. miles), averaged 14.6 in. for the same period, and the maximum daily discharge was 48.7 cu. ft. per sec. per sq. mile. Considering the fact that unit run-off for the same conditions is always less, the greater the water-shed, this result is quite remarkable. It is undoubtedly due to the action of the Sierra forests on snow-melting, and again illustrates the inability of forests to exercise any restraining influence upon great floods.*

*In the paper, "The Flood of March, 1907, in the Sacramento and San Joaquin River Basins, California," by Messrs. Clapp, Murphy and Martin, published in *Transactions*, Am. Soc. C. E., Vol. LXI, p. 281, the authors say, "In the Sierras the greater part of the precipitation is normally in the form of snow, and the magnitude of floods depends largely on the rate of melting. A heavy warm rain on deep, freshly fallen snow produces a maximum run-off."

TABLE 1.—Gauge Records of Certain Rivers of the United States.

Highest and Lowest Stages for Each Year.

Mississippi.

Year.	St. Paul.		St. Louis.	
	Highest.	Lowest.	Highest.	Lowest.
1785	....	....	40.6*	....
1826	....	....	? 33.7	....
1828	....	....	36.4	....
1838	....	....	27.0	....
1843	....	....	27.2	....
1844	....	....	41.3	....
1845	....	....	32.4	....
1846	....	....	25.0	....
1849	....	....	27.4	....
1851	....	....	36.5	....
1852	....	....	28.0	....
1853	....	....	30.0	....
1855	....	....	37.1	....
1856	....	....	27.4	....
1858	....	....	37.0	....
1860	....	....	....	0.6
1861	....	....	25.5	1.3
1862	....	....	31.5	3.5
1863	....	....	18.0	0.0
1864	....	....	20.3	1.2
1865	....	....	26.8	1.2
1866	....	2.2	26.8	5.6
1867	....	3.0	28.2	1.2
1868	....	2.0	24.1	1.0
1869	16.1	2.8	29.2	4.7
1870	....	....	26.2	5.2
1871	....	....	21.8	2.8
1872	? 7.7	1.9	23.0	2.4
1873	16.4	2.4	25.5	4.6
1874	11.6	3.0	18.4	2.8
1875	18.0	2.1	30.0	2.3
1876	11.0	1.9	31.8	5.0
1877	7.7	1.8	26.5	7.0
1878	6.7	0.6	25.7	5.6
1879	10.8	0.9	21.2	3.4
1880	15.3	1.7	25.5	2.7
1881	19.7	3.3	33.6	7.6
1882	13.3	2.9	32.0	2.8
1883	12.5	1.5	34.8	4.5
1884	10.3	1.8	28.1	3.0
1885	7.4	1.9	27.1	2.0
1886	8.2	1.2	27.0	1.4
1887	9.6	0.8	20.6	0.9
1888	14.4	2.4	29.4	3.2
1889	4.5	0.8	24.6	2.5
1890	7.0	0.6	20.5	2.8
1891	6.4	0.1	23.7	3.0
1892	12.6	1.0	36.0	1.0
1893	14.7	0.6	31.6	— 0.2
1894	11.8	0.2	23.3	0.2
1895	4.6	0.2	23.4	— 0.5
1896	10.7	0.9	27.7	3.7
1897	18.0	2.3	30.9	— 0.5
1898	10.7	2.8	27.2	0.3
1899	11.0	2.4	25.7	— 1.0
1900	6.6	0.7	23.5	— 2.5
1901	7.5	1.2	22.5	— 2.0
1902	7.5	1.1	26.8	— 1.0
1903	13.5	2.5	38.0	0.6
1904	9.9	2.6	33.6	— 0.1
1905	14.8	2.0	30.2	— 0.3
1906	13.3	4.9	26.2	3.0
1907	13.6	1.3	....	....

* "L'année des grandes eaux."

TABLE 1.—(*Continued.*)

OHIO.

Year.	Pittsburg.		Cincinnati.		Louisville.	
	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.
1810	32.0	.....	....	....	Upper	Gauge
1813	29.0	.....	....	....	....	....
1816	33.0	.....	....	....	....	....
1832	34.0	.....	64.2	....	40.8	....
1840	26.9	.....	....	....	....	....
1846	25.0	.....	....	....	....	....
1847	26.0	.....	63.6	....	....	....
1848	23.0	....	....	....	....	....
1851	30.9	.....	....	....	20.3	1.5
1852	31.9	.....	....	....	....	....
1853	31.9	.....	....	....	....	....
1855	18.0	2.1	....	....	....	....
1856	19.6	0.3	....	....	....	1.1
1857	21.4	0.0	....	....	....	....
1858	26.0	0.5	43.1	2.5	19.1	1.5
1859	22.0	1.1	55.5	3.3	33.8	2.6
1860	29.7	2.8	49.2	5.3	....	....
1861	30.9	1.1	49.4	5.1	....	....
1862	30.0	0.3	57.3	2.3	....	....
1863	16.0	0.1	42.7	2.5	....	....
1864	18.6	1.0	45.1	3.1	....	....
1865	31.4	1.4	56.2	5.7	....	....
1866	15.4	0.4	42.5	4.7	18.6	2.8
1867	22.6	0.0	55.7	3.0	37.6	1.8
1868	20.6	0.0	48.2	5.1	22.3	3.0
1869	19.6	0.7	48.7	5.3	24.3	2.8
1870	18.0	1.3	55.2	3.8	....	....
1871	19.0	1.2	40.5	2.7	....	....
1872	20.6	1.6	41.7	3.0	21.0	2.0
1873	25.6	1.6	44.4	3.7	18.3	2.3
1874	22.4	1.1	47.9	2.3	22.4	1.8
1875	25.0	0.4	55.3	4.2	30.3	2.7
1876	26.0	0.2	51.7	6.2	32.5	3.7
1877	25.0	0.7	53.7	3.2	29.9	2.2
1878	24.6	0.0	41.3	4.3	15.7	2.9
1879	20.0	0.1	42.7	2.5	19.6	2.2
1880	22.0	0.3	53.1	3.7	30.0	2.8
1881	28.0	0.6	50.6	1.9	22.5	1.7
1882	21.9	0.6	58.6	6.1	37.4	4.7
1883	27.6	0.1	66.3	3.6	43.8	3.2
1884	34.4	0.3	71.0	2.7	46.7	2.0
1885	23.0	1.0	46.0	2.5	22.2	2.9
1886	22.8	0.3	55.7	3.3	32.7	2.4
1887	22.0	2.0	56.2	2.7	32.5	2.2
1888	26.0	0.0	39.9	5.2	16.1	3.6
1889	24.0	0.2	38.2	5.2	13.8	3.5
1890	24.3	1.2	59.2	5.7	35.3	3.6
1891	31.3	1.9	57.3	4.4	32.4	2.8
1892	23.0	1.3	43.7	3.4	21.9	2.1
1893	24.0	1.5	54.9	3.6	28.8	2.0
1894	25.2	2.0	35.6	3.1	12.8	2.2
1895	25.8	1.2	48.4	2.3	20.7	1.8
1896	23.0	2.0	47.8	5.5	22.4	3.9
1897	29.5	1.7	61.2	3.1	35.3	2.4
1898	28.9	2.2	61.4	4.5	36.3	3.1
1899	22.0	2.4	57.4	3.4	32.8	2.2
1900	27.7	1.6	40.0	3.2	15.4	2.0
1901	27.5	0.8	58.7	4.2	33.2	2.8
1902	32.4	1.1	50.9	3.9	24.8	2.8
1903	28.9	0.0	53.1	4.5	28.7	2.8
1904	30.0	1.7	45.9	3.3	22.9	2.0
1905	29.0	1.0	48.2	6.5	22.0	3.1
1906	18.5	0.0	50.2	7.1	26.4	3.1
1907	35.5	0.0	65.2	7.0	41.2	3.4

TABLE 1.—(*Continued.*)

TENNESSEE.

Year.	Chattanooga.		Florence.	
	Highest.	Lowest.	Highest.	Lowest.
1867	58.6	....	31.1	....
1871	....	....	....	0.0
1872	....	....	16.4	−0.8
1873	....	....	22.9	−0.5
1874	....	0.7	26.0	0.0
1875	54.0	2.2	29.4	0.4
1876	31.1	1.0	19.8	−0.6
1877	28.7	1.2	19.4	0.0
1878	19.2	0.9	13.6	−0.8
1879	38.0	0.2	21.5	−0.5
1880	38.3	1.0	24.5	0.1
1881	22.4	0.0	17.4	0.0
1882	40.2	1.7	29.6	1.2
1883	38.2	0.0	23.3	0.4
1884	42.8	0.2	25.2	0.3
1885	30.4	0.7	17.8	0.6
1886	52.2	1.2	28.1	0.5
1887	27.3	1.2	17.5	0.5
1888	27.0	1.8	20.8	0.7
1889	29.6	2.1	19.7	1.2
1890	42.5	2.0	28.3	1.7
1891	38.9	1.2	22.2	1.0
1892	37.9	1.1	24.0	0.8
1893	33.4	1.6	21.4	1.1
1894	25.5	0.7	17.7	−0.1
1895	32.1	0.7	17.5	0.0
1896	40.5	1.1	20.0	0.1
1897	37.9	0.4	32.2	−0.5
1898	24.6	1.6	13.8	0.4
1899	40.0	0.8	25.2	−0.1
1900	24.3	1.0	19.5	0.1
1901	37.4	2.1	18.9	0.8
1902	40.8	1.2	21.7	−0.4
1903	31.8	0.6	18.8	−0.5
1904	22.1	0.1	17.2	−0.5
1905	22.4	1.2	16.7	0.0
1906	33.3	3.2	16.7	1.5

TABLE 1.—(*Continued.*)

Missouri.			Connecticut.		
Year.	Kansas City.		Year.	Springfield.	
	Highest.	Lowest.		Highest.	Lowest.
1844	36.0*	....	1801	21.0	....
1873	19.3	2.0	1843	20.4	....
1874	16.2	1.5	1854	22.2	....
1875	17.8	1.8	1862	22.0	....
1876	18.0	2.0	1869	20.4	....
1877	22.2	3.8	1871	13.0	0.10
1878	19.8	3.5	1872	14.2	1.10
1879	19.2	3.2	1873	15.0	0.6
1880	16.7	?2.0	1874	17.5	1.0
1881	26.3	3.0	1875	15.0	0.8
1882	19.2	1.2	1876	17.0	0.6
1883	23.8	?5.0	1877	16.5	1.2
1884	?17.2	?3.0	1878	18.5	1.2
1885	19.1	3.8	1879	15.8	1.6
1886	15.8	0.2	1880	10.8	1.0
1887	20.2	1.8	1881	11.5	1.7
1888	20.4	4.7	1882	10.9	1.6
1889	13.9	3.2	1883	14.6	1.8
1890	17.2	0.2	1884	16.0	2.2
1891	23.1	2.5	1885	13.3	2.4
1892	24.9	1.5	1886	16.0	1.6
1893	18.1	3.1	1887	17.0	2.1
1894	20.1	4.3	1888	17.7	2.2
1895	16.9	3.3	1889	11.3	3.2
1896	19.2	2.8	1890	11.7	2.8
1897	22.8	2.0	1891	14.3	2.8
1898	21.5	4.0	1892	13.8	3.0
1899	23.3	5.2	1893	18.2	2.1
1900	17.8	4.2	1894	10.4	2.6
1901	19.4	3.7	1895	20.2	3.4
1902	23.2	3.5	1896	20.2	3.5
1903	35.0	3.5	1897	15.3	3.8
1904	25.2	2.1	1898	15.5	3.8
1905	23.0	2.0	1899	16.2	3.6
1906	19.7	2.3	1900	17.0	3.6
1907	24.0	4.1	1901	19.8	3.6
1908	30.5	3.7	1902	19.3	3.1
			1903	17.4	3.1
			1904	15.3	3.1
			1905	17.6	3.6
			1906	15.1	3.0
			1907	15.5	3.3

* Approximately.

During the spring of 1908 occurred a record-breaking flood in Western Montana, nearly all the streams on both sides of the Continental Divide going far over their banks. As might have been predicted, this occurrence was promptly cited as another example of the effect that a forest-barren country has upon floods. Nevertheless it is as certain as anything of this kind can be, that if the country affected by this extraordinary downpour (in some places breaking all previous records) had been thickly forested, and the ground still covered, as it would have been, with a solid layer of saturated snow, the flood would have far exceeded in magnitude and destructiveness that which actually took place. Wherever forests existed in the higher altitudes they did have this effect.*

Having now considered the influence of forests upon stream flow from a theoretical standpoint, let the records themselves be examined as far as they are available. These records in the United States, unfortunately, are not so useful as might be wished, because of their brevity. No continuous records on any of our streams run back for more than eighty years, and most of them less than half as far. This is far short of the 200 years considered by certain European engineers who investigated Wex's theories as the minimum period "necessary in order to draw a reliable conclusion" upon this subject. It does indeed seem absurd to take present-day records, as is constantly done, and draw conclusions one way or the other as to comparisons with the past, of which records are entirely wanting; but such as they are, a few of these records are given in Table 1. They include in most cases both high and low water, although the low-water records cannot, in the nature of the case, be of very much value. Works of channel improvement on most of the streams have probably affected somewhat the low-water stages for the same discharge, while, as is well known, a given stage, even in a natural stream, does not mean the same discharge at different times.† It is really the discharge of the streams rather than the stage that forms the correct basis for comparison; but data for discharge are almost wholly wanting.

An examination of these records shows how utterly impossible it is to find anything in them to support the current theory of forest

*In the Weather Bureau report, Montana section for June, 1908, it is stated that "the rainfall was phenomenally heavy over most of this district, and, combined with the water from the rapidly melting snow in the high mountains, caused unprecedented floods in nearly all streams."

†During the past 20 years the low-water stage of the Mississippi at St. Paul has been materially modified by reservoir action.

FIG. 1.—DESTRUCTION FROM FRESHET IN WHITE RIVER, WASHINGTON.

FIG. 2.—NEW GROWTH OF TIMBER, ABOUT SIX YEARS AFTER FIRE.

influence. They prove conclusively that there has been no marked change since the settlement of the country began, and that such change as there has been is on the side of higher high waters and lower low waters before the forests were cut off. What the record would be if we could go back 200 years cannot be said, but it may safely be conjectured that it would show both floods and low waters that would equal or surpass any modern record. It is the experience of every engineer who has the opportunity to observe the action and study the history of great rivers to find everywhere evidence of the occurrence of higher waters than any of which he has positive record. The up-building of bottom lands, the survival of old water marks, and many other indications, show that, great as are modern floods, those of the past were greater still. In the very nature of the case, it is not possible to find similar evidence of former low waters, because such evidence is wiped out by every succeeding high water; but whoever will take the trouble to study records of early expeditions on our rivers, when barges, keel boats and similar craft were used, will conclude that extreme low water is not a modern development by any means. Measurements of the Monongahela River, at Brownsville, in 1838 and 1856, low-water years, gave discharges of 75 and 23 cu. ft. per sec., respectively. It is quite certain that the river has not fallen so low in late years. At Pittsburg in 1895 (the dryest season in recent years), it fell to 160 ft.

The point should be fully recognized that these records are valueless for establishing either side of the forestry argument unless they clearly indicate a new tendency in river flow. It is not enough to cite a few isolated cases. In a period of, say, 200 years, there must be a record year for high and one for low water. Is there any reason why it might not occur this year as well as earlier? There must be clear evidence of permanent change before any conclusion can be legitimately drawn. In two instances such a tendency may possibly be claimed, the Ohio at Pittsburg and the Connecticut at Holyoke, which show, in the past few years, a greater frequency of high waters than for some years previously.* To whatever extent this may be true, it

*In the period of 34 years from 1874, the Ohio River at Pittsburg rose above 15 ft. on the gauge 148 times. In the first half of this period, 68 of these freshets occurred and 80 in the second half. The mean for the first half was 19.3 ft. and 20.2 ft. for the second half. The mean of the lowest waters of the first half was 0.3 ft. and 1.6 ft. for the second half. In *Transactions*, Am. Soc. C. E., Vol. LVIII, p. 31, is a 20-year volumetric record of the Connecticut, which indicates somewhat higher high waters during the last half of the period. But in this case, as at Pittsburg, higher low waters are also indicated. In fact, in both cases, the greater run-off in the later period was clearly due to greater precipitation.

is certainly not due to deforestation. The change in the forested areas on the water-sheds of either of these streams has been relatively very slight in the past 20 years. The great inroad into the timber of the Upper Ohio took place many years ago. Since that time many cleared areas have grown up to timber while new areas have been cut. The change one way or the other, in recent years, compared with the total area, is altogether insignificant. The Connecticut water-shed above Holyoke has a greater forested area than it had 40 years ago. This is due to the abandonment of former farms which, in many instances, have grown up to timber. It is doubtful if the recent cutting in the White Mountains offsets this, and, so far as snow-melting is concerned, what cutting there has been is certainly in favor of uniformity of flow.*

The records of some American rivers have been given. It is, of course, in Europe that one would expect to find more definite data because of the longer periods through which records have been kept. The histories of several of these streams have been examined without finding any confirmation whatever of the forestry theory. The floods on the River Seine, for example, show greater heights in the 16th century than in the 19th. The most exhaustive investigation of the records of European rivers, however, is that of the Danube, the great river of Central Europe, recently made by Ernst Lauda, Chief of the Hydrographic Bureau of the Austrian Government. The years 1897 and 1899 brought destructive floods to the Valley of the Danube, that of 1899 being particularly severe. M. Lauda prepared an exhaustive report upon this flood, published in 1900, accompanied by elaborate maps and tables and a searching analysis of the climatic and other conditions. In his "Concluding Remarks," M. Lauda traces the history of the Danube floods for 800 years, including in all 125 floods. His conclusions are that floods were formerly just as frequent and as high as they are in recent times, and that the progressive deforesta-

*"I have seen in the last few years abandoned farms (abandoned because of their unprofitableness) on the Western slopes of the Allegheny Mountains, which are almost impenetrable forests of thrifty trees suitable for making mine posts and telegraph poles. There are, of course, large areas subject to fires at intervals of a few years, but that they are subject to such recurrent fires is proof of their rapid production of fuel which means twigs and leaves in great abundance." (Col. Thomas P. Roberts, Pittsburg, Pa.)

"The forest area in Vermont is probably 10 per cent. greater than forty years ago. Of course the quality of the forest is inferior, but that has no effect on the water-shed." (Arthur M. Vaughan State Forester.)

"Farms in the Connecticut Valley are among the richest in the state [New Hampshire] and have been less abandoned than elsewhere. There has been, however, a goodly acreage, very probably amounting to 25 per cent., which was cleared land in 1850, and which at the present time has reverted to forest; much of it excellent white pine forest." (Philip W. Ayres, Forester.)

tion of the country has had no effect in increasing them. In fact the records of the flood of 1899, which was a summer flood, produced almost entirely by rain, showed that it was severest on those very parts of the water-shed that were most heavily forested.

At the 10th International Congress of Navigation, held at Milan in 1905, one of the four questions appointed for discussion was the very one here under consideration. Papers were presented by representatives from France, Germany, Italy, Austria and Russia. While all the writers heartily favored forest culture, the opinion was practically unanimous that forests exert no appreciable influence upon the extremes of flow in rivers. It appears, therefore, that European experience does not support the currently accepted theory.

So much for the evidence supplied by the records in this country and abroad. The constantly reiterated statement that floods are increasing in frequency and intensity, as compared with former times, has nothing to support it. There are, it is true, periods when floods are more frequent than at others, and hasty conclusions are always drawn at such times; but, taking the records year after year for considerable periods, no change worth considering is discoverable. The explanation of these periods of high water, like the one now prevailing, must, of course, be sought in precipitation. That is where floods come from, and it is very strange that those who are looking so eagerly for a cause of these floods jump at an indirect cause and leave the direct one entirely untouched. In the records of precipitation, wherever they exist, will be found a full and complete explanation of every one of the floods that have seemed unusually frequent and severe in recent years. A few examples will be cited:

The great Kaw River flood of 1903, which wrought such havoc in Kansas City, was caused by a wholly exceptional rainfall over nearly all the water-shed of that stream. In the first three weeks of May, 1903, more than the normal amount (4.5 in.) for the entire month fell. This was followed in the next five days by 3.4 in., and upon this was piled 4.7 in. in the succeeding five days, by which time the flood had crested.

In the flood of 1906 in Western Washington, which did enormous damage and stopped railway traffic for upward of two weeks, the crest of the flood occurred about the 15th of the month. The month of October had been very wet, and the ground and forest storage was

exhausted. In the first half of November, 25% more rain fell than in the normal for the entire month, and of this about one-half came on the 13th, 14th, and 15th.

In the flood season of 1905 on the water-shed of the Upper Mississippi, there fell in the month of April above Pokegama Falls 2.55 in., in May, 4.95 in., in June, 8.03 in., and in July, 6.88 in., a total of 22.41 in. The normal for the entire year is 26.5 in.

In the record-breaking flood of 1907, in the Sacramento Valley, 88% of the normal for the month of March (based on 21 years' observation) fell in three days (17th-19th), and, on one day, the precipitation ranged from 5 to 8 in. at the different stations.

In the extraordinary flood of May and June, 1908, in Western Montana, the precipitation for May, at four selected stations, was 6.5 in., and for June, 4.2 in. The greater portion of this fell late in May and early in June. The normal for May is 2.6 in. and for June, 2.3 in.

Similar conditions prevail in every great flood, and the true explanation is found in them and not at all in the presence or absence of forests on the water-sheds. Whether the forests are in any way responsible for the precipitation itself, and so, indirectly, for the floods, brings up the third of the foregoing general propositions, viz., that forests do increase precipitation. However strong may be the popular belief in this theory, there is nothing in the records of rainfall to give it substantial support. The writer has had occasion, in connection with his official work, to compare the rainfall records in the northern half of the United States from the Atlantic to the Pacific, often with this particular point in mind, and he has never found anything to indicate a change. So far as he has examined European records the same result holds, and he believes it to be true the world over except where climatic changes have resulted from causes entirely disconnected with the operations of Man in changing the face of Nature. In fact, the claim that forests increase precipitation (about 10%, according to Mr. Pinchot) leads to some contradictory results in the forestry argument. Coincident with our recent high waters, which are attributed so largely to deforestation, there has been an increase in precipitation, where there should, apparently, have been a decrease.* It is evident that, where one rule applies, the other fails.

*As a step in the crescendo of gloomy forebodings upon this subject, that have filled the periodicals during the past twelve months, the following from the September *Scrap Book* is the very latest: "When our forests are gone the streams will

So, likewise, it is held that forests are necessary to protect mountain slopes because of the greater precipitation prevailing there; yet the forests are said to increase this precipitation materially.

There is really very little, theoretically, to support the claim that forests increase precipitation. It is said that the cooler status of forest areas condenses moisture and induces precipitation; but if this were so in midsummer, when the least precipitation falls, how about the rest of the year when no such difference exists, but the reverse, if anything? Take, for example, the great forests around the source of the Yellowstone. During the period when the bulk of the precipitation falls, the temperature of the forests cannot differ materially from the outside, and it is impossible to believe that the forest exercises much influence upon the snowfall.

The fact that these high areas are generally wooded is frequently cited to prove that forests produce the higher rates of precipitation which also prevail there. But would it not be more reasonable to say that the forests flourish there because of the higher precipitation, and that the latter is due to the elevated situation and consequent lower temperature? Is not this, in fact, the reason why precipitation is nearly always greater upon the hills than upon the neighboring lowland? The mountains are Nature's wine-press by which she extracts from an unwilling atmosphere the elixir of life for the hillsides and the valleys below, and she does this whether the forests have been cut away or not.

In one respect, and a very important one, forests diminish precipitation, and that is in the deposition of dew. Dew is essentially an open-country phenomenon, where the radiation of heat from the earth's surface is unobstructed. Clouds or high cover of any kind, and also wind, interfere with this process and prevent the dew from gathering. It collects in full strength on low shrubbery, to a less degree on small trees, as in orchards, and penetrates for short distances under forest cover. In the heart of the native forest of full-grown timber, however, dew is practically unknown. The quantity deposited in the open country in a single night is quite large under

dry up, the rivers will cease to run, the rain will fall no more, and America will be a desert!" Considering how large a percentage of our forests has already disappeared, the extraordinary rains in all parts of the United States during the past year are not exactly in line with this dismal prophecy. If one were to judge from the records of the past few years only, he must conclude that deforestation is increasing rainfall.

favorable conditions, leaving the effect on shrubbery and on the ground of a considerable shower. As it gathers in greater or smaller quantities on every clear, still night in the eastern sections of the country, except in the colder season of the year, the total quantity must be quite large.*

One authority holds that dew does not come entirely from the air, but in part from the ground. It is said that water, which in the daytime passes from the ground and plants into the air, is prevented from doing this at night, because the air cannot receive it, and, therefore, it gathers in visible form on the ground and vegetation; but if this were true, it really makes no difference in the benefit which comes from the dew. Whether the low temperature due to radiation causes a deposit of moisture from the air or prevents the air from absorbing moisture which it otherwise would, the result, so far as the ground and vegetation are concerned, is practically the same.

This may be as good a place as any to note one important characteristic of precipitation, and that is its tendency to move in cycles. It is well known that dry years often follow each other for long periods with great regularity, and that these are succeeded by wet periods. Take the region of the Upper Mississippi reservoirs where the normal precipitation, based upon 21 years' observation, is 27.1 in.; in the ten years (1886-1895), this normal was exceeded only once; in the succeeding ten years the record fell appreciably below it only once. Omitting these two years, the mean for the two periods of 9 years was 24.7 and 30.0 in., respectively, an average yearly difference of nearly one-fifth of the normal. Following the well-known law that the percentage of run-off increases and diminishes with the precipitation, the disparity between the run-offs for the two periods was greater still.

This phenomenon is also admirably illustrated in the rise and fall of the levels of the Great Lakes, for these immense storage reservoirs, not only absorb and distribute annual variations of run-off, but equalize to a large degree the variations from year to year. During the period of the Eighties, there was a general rise in the lake levels except Superior,

*The writer has never seen any data as to the actual quantities of dew deposited in different localities and conditions, and hopes that the discussion of this paper may bring some to light. He has, however, vivid recollections on the subject when, as a lad on a dairy farm, it was his unlucky lot to go barefooted after the cows every morning without waiting to see whether the sun was going to shine or not. He knows from experience how near zero the dew point can get, and how wet dew is; and also that the warmest place in the world, at such times, is where a cow has lain all night, and next to that the dry precincts of the tall woods.

and many people ascribed this fact to deforestation, which allowed the water to find its way more quickly into the lakes. During the Nineties, there was a period of general subsidence, occasioning considerable anxiety, and it was frequently asserted at that time that this was due to deforestation, which was drying up the streams. For some years now the Lakes have been rising, Ontario being the highest in 40 years; and with another wet year the levels will almost reach record heights.

The long record of the Danube floods, already referred to, is another example. Almost invariably high floods would follow each other for several years in close succession, and then would come long intervals of ordinary high waters.

These periodic changes are not, of course, due at all to the presence or absence of forests, for they occur just the same whether forest conditions remain unchanged or not. It is an order of Nature not at all understood, but nevertheless fully established as a fact. Just now we are in an era of high precipitation and consequently of high waters. There is a disposition to "view with alarm" these exaggerated conditions. Rarely does one stop to think how far better it is to the country to have these wet periods, even with all their floods, than the dry periods that will surely follow. A single dry year may cause more loss to the country through the shrinkage of crops than the floods of an entire cycle of wet years.

Related to the subject of precipitation is that of evaporation as affecting the quantity of water that remains upon the ground. Generally speaking, the surface evaporation in summer should be greater in the open than in the forest because of the more direct action of the sun and wind; but in the height of summer the forests arrest precipitation to such an extent in the leaves and humus, that more of it escapes through evaporation than in the open. The effect of forests upon evaporation through the medium of their leaves finds its counterpart in the similar action of the growing crops that overspread deforested areas. As already pointed out, the forests of the mountains increase the evaporation from snow very materially.

Where the balance lies among all these conflicting influences affecting precipitation and evaporation it is impossible to say, and when the records are examined it must be admitted that they afford no answer. So far as the researches of Science have yet determined, the presence or absence of forests cuts no figure in climatic conditions.

These depend upon causes of far greater magnitude, and are influenced, if at all, only to an insignificant degree by the operations of those who occupy the planet.

The fourth proposition of the forestry argument is that forests are necessary to prevent erosion on steep slopes and the consequent silting of reservoirs and watercourses below. Here again there is the same deficiency of evidence to support the theory that has characterized the three propositions already considered. The writer has been unable to find anything to confirm it. In his observations, embracing pretty nearly all varieties of timber land in the northern two-thirds of the United States, he has still to see a single example where the mere cutting off of forest trees has led to an extensive erosion of the soil. Almost invariably, and it may be said always except in very unusual conditions, a soil that will sustain a heavy forest growth will immediately put forth, when the forest is cut down (or even burned down), a new growth, generally in part different from the first, but forming an equally effective cover to the soil. The only approach to an exception to this rule that he has observed is in some of the high mountain forests where the soil is extremely thin and weak and the action of Nature in producing vegetable growth is slow. Fig. 2, Plate XL, shows one of the best examples of this class of timber land; but even here the slow growth is very evident and no large amount of soil erosion has resulted. In the forest areas of the East, the growth that follows tree-cutting, consisting not only of new trees but of briars and small brush of every description, accumulates very rapidly and forms a more effective mat against erosion than the original forest itself and is equally effective in storing water. Such low growths have also a better effect upon snow-melting because they give both wind and sun freer play. Certainly the ground in a forest under culture, with the débris raked up, is more easily eroded than that of a slashing or second-growth area, or even good meadow or pasture. A forest soil unprotected by forest débris is almost as erosible as a field under culture.

The increased erosion of the soil, of which so much is heard, does not result from forest cutting, but from cultivation, using that term in its broad sense to include all of Man's operations for the occupancy and utilization of the ground from which the forests have been removed. It is the "breaking of the soil" that leads to its

erosion by the elements. Roads and trails are one of the great sources of erosion in hilly countries, but plowing and tilling are the principal causes. The question is not one of forests in the first instance, but of how far the cultivation and occupancy of the soil can be dispensed with. Even on steep mountain slopes, where erosion and ruin have resulted, the effect is often due to the clumsy and injudicious work of the husbandman who uses no judgment of cause and effect in the way he exposes the soil to the force of the storms. The successful cultivation of hillsides in every quarter of the globe is an everlasting refutation of the argument that forests are necessary to protect the face of the earth wherever cultivation is practicable. Some classes of cultivated vegetation, like the well-knit turf of meadow or pasture, are a better protection against erosion than any ordinary forest cover. That there are sections of the country where erosion of the soil is much more rapid than in others under similar conditions, is perfectly true. This is especially the case with certain districts in the Southern States, and very likely forest protection is there better than any other; but it is still true that the problem of control of soil erosion on cleared lands is essentially a problem in cultivation. It is not so much the absence of the forest as it is the cutting of roads and ditches, the upturning of the soil, and the various kindred operations of Man that quicken the run-off and increase the surface soil wash.

The oft-repeated assertion that, owing to the cutting off of forests, our rivers are shoaling up more than formerly may be challenged absolutely. There is nothing in our river history to support it except in a few instances, like the Yuba River in California, where extensive hydraulic or similar operations have produced vast changes. It is exceedingly doubtful if it can be established by any evidence worthy of the name that the streams of the Mississippi Basin are more obstructed by sand bars than formerly. The writer's observations of upward of 20 years and inquiries from many sources fail to disclose any such evidence. It would not, indeed, be surprising if some such result were noticeable, for it would naturally seem that the cultivation of the soil has facilitated to some degree the wash into the streams. If this is the case, however, the rivers do not show it. They have a way of distributing their burdens so as to meet their

necessities and, except in rare cases, they do not shoal appreciably more than formerly.*

The distinction between erosion actually resulting from cultivation, and that assumed to result from timber cutting, is important to keep in mind, for it fixes the burden of responsibility where it belongs. It shows that this erosion or soil wash can be reduced only by the elimination or control of cultivation, and the question at once becomes that of the extent to which such control or elimination is practicable. For example, it is insisted that the suggested reservoir system of the Ohio, to be referred to later, will be absolutely dependent for its integrity and permanence upon keeping the water-sheds above them covered with forests. But it is understood not to be the policy to include in the proposed forest reserves any lands that are fitted for agriculture.† As elsewhere pointed out, that portion of these areas, which is not reduced to cultivation, will not be subject to erosion more than at present by the mere fact of cutting off the timber; for the natural growth on logged-off lands is just as good a protection as the forests themselves. If the agricultural tracts are still to be left open for occupancy, the source of sediment remains uncurbed and the whole argument for forest reserves, on the ground of protecting the reservoirs from sedimentation, falls to the ground.

Some reference should be made to the real significance of the alarming reports which have been put forth concerning the washing of our soils into the sea. Over and over during the past year has the statement appeared that 1 000 million tons of our soil is annually carried by our rivers into the ocean. This figure itself is quite conservative, but the conclusions drawn from it are not at all so. Taking the results of silt observations on the Mississippi River and its tributaries for 1879, and applying the Missouri rate to all Western streams outside the Mississippi Basin, and the Ohio rate to all Eastern streams outside the same basin, a total of about 1 100 million tons is indicated.

*The absurd length to which this erosion argument has been carried is well illustrated by the remark made in a recent address by one of the officials of the Forestry Service: "This energy [of running water] is expended in rolling along stones and gravel to finally build up the mouths or beds of the great rivers. Next year there will be a bill introduced in Congress providing a forest reserve in the Appalachian Mountains, so that the rocks from these mountains will be kept from the Mississippi River!"

†Among references to the intention not to absorb agricultural lands in the areas conserved by the reservoirs is the following from A. F. Horton, Assoc. M. Am. Soc. C. E., in *Engineering News*, June 11th, 1908: "The reader should not lose sight of the fact that the conserved area is not rendered unfit for cultivation or other use, but that only a small portion of the conserved area [that covered by the reservoir] is so utilized that its value for cultivation is destroyed."

But 1879 was a low-water year in the Mississippi Basin and the quantity for average years may probably be 1 500 million tons and for extreme years, 2 000 million tons.

Let us look these prodigious quantities squarely in the face and see what they mean. Where does this enormous volume of soil come from? Is it, as one might infer from published references to the subject, from our cultivated fields—an annual toll laid upon the precious fertility of our agricultural lands? Not at all. Only a very small proportion comes from this source. Possibly half of the total quantity of sediment goes down by the Mississippi. All authorities agree that the greater portion of this comes from the Missouri. From computations which the writer has made, he believes that fully two-thirds of it comes from that source. The observations of 1879 indicate that five times as much sediment comes from that stream as from the Ohio. But where does the Missouri get it? Almost entirely from the most useless areas of land with which any country was ever afflicted. The barren Bad Lands are the principal source. Much comes from the mountains; much from the sand hills; very little, relatively, from cultivated areas. Of the remainder of the soil wash of the United States, by far the greater portion comes from other similar sections of the West where the streams carry enormous loads of sediment. The entire Colorado system is even more distinguished in this respect than is the Missouri. The same is true of the Rio Grande, the Pecos, and the upper courses of the Arkansas and Red. Even the streams of the Great Interior Basin are heavy silt bearers, and the same is true of many of the streams of the Pacific Coast. The streams flowing into Puget Sound are heavily laden with silt at certain portions of the year, and the great Columbia Bar is impressive evidence of the vast burden of sediment which that mighty river has carried to the sea. Nearly all the annual load carried by these streams is entirely unaffected by anything which Man has done. It is the regular natural carving down of the hills and building up of the valleys and estuaries below.

The Eastern streams are clear and sediment-free compared with those of the West; but even in these, a large portion of their sediment is eroded from the gorges and cañons of the hills and mountains, which will continue to wash away as long as the rivers flow. This particular class of erosion, on both Eastern and Western rivers, is far less objec-

tionable than one is led in these later days to believe. Has it not from the beginning been one of the most beneficent operations of Nature? Are not the richest lands in the world—the river bottoms and deltas—built up in this way? To a very great extent the irrigated lands of the West are composed entirely of the débris from the mountains and the bad lands. Even to-day this tribute from the highlands is of great value. The periodic enrichment of the Ohio bottom lands and similar tracts in hundreds of other places, is of the highest economic importance. The soil-laden waters of irrigation in the spring, though sometimes injurious to the growing crop for the time being, are, on the whole, extremely beneficial. The damage from sediment is not in its injury to the lands ordinarily, but to ditches, canals, reservoirs and similar works. On the whole, it is, and always has been, a benefit to the lowlands. Even that portion carried out to sea builds up deltas and surely, though slowly, extends the habitable area of the globe. Not alone in the resources of water and timber, but in the perpetual renewal of soil as well, has the valley said to the mountains throughout the world's history: "I will lift up mine eyes unto the hills from whence cometh my help."

Sediment of this character, except when accompanied by alkaline salts or other similar ingredients, is not injurious to domestic supply. The water of the Missouri River is one of the healthiest drinking waters in the world in spite of the fact that it is one of the muddiest.*

The proportion of soil wash that comes from cultivated fields is really very small compared with the enormous total that the rivers carry away. Heavy rains undoubtedly wash farm soils a great deal, but this erosion is in large part a transfer from one spot to another and not an absolute loss. The history of the old Ohio Canal reservoirs indicates very little filling in the 66 years that they have been in existence. According to the Chief Engineer of the Ohio State Board of Public Works, it is scarcely appreciable in some of the reservoirs and in none does it amount to as much as 6 in., or $\frac{1}{200}$ in. per year from the tributary water-shed. Yet these reservoirs are surrounded by rich agricultural lands. The silt observations on the Ohio in 1879 indicate only a little more than $\frac{1}{600}$ in. over the entire water-shed; but this, it is true, was a year of light rains.

*The late J. B. Johnson, M. Am. Soc. C. E., used to say, in extolling the virtues of Missouri River water, that it was the most perfectly filtered water in the world: with this difference, however, that in the ordinary case water is run through the filter, but here the filter is run through the water.

It is readily seen that the formidable danger of which so much has been written of late becomes quite harmless as to quantity when it comes down to the individual farm. The harm is probably not so much in the quantity of soil actually lost as in the fact that the soil may be leached of some of its more important ingredients. The evil is one which can be controlled only by better methods of farming, whereby the surface waters will be restrained from eroding the soil; but even these measures have their adverse side, for when heavy rains prevail for a long time it is more important to the farmer to get the water off his land than it is to save a little soil. Most of the soil will stop on lower ground and not be wholly lost, but if the water is not gotten rid of the crop may be ruined.

The caving of the banks of our great rivers is constantly cited as an example of soil loss on an enormous scale, and it is asserted that this condition is worse now than formerly. The Mississippi and Missouri Rivers, practically alike in this respect, are the two most prominent examples. The writer will consider briefly the case of the Missouri because he has had a long and intimate acquaintance with that stream from its mouth to its source.

It may be stated by way of refutation that the actual condition of this stream to-day is better than before settlement began in its valley, except that possibly the low-water flow is slightly diminished to meet the demands for irrigation. The stream is not "constantly becoming more and more savage," as a recent writer asserts. On the other hand, its natural savagery is much restrained. Probably 100 miles of its banks are protected; snags and drift heaps are largely removed; considerable bottom land has been reclaimed and turned to industrial use; floods are no greater than they used to be, and navigation is safer and easier. Navigation has ceased, not because the river has deteriorated, as is commonly asserted, but because the natural difficulties peculiar to this stream are so great and so hard to overcome that boats cannot live and do business at the same rates at which railroads transport freight.

That the river is a most destructive one to the bottom lands along its course is only too true; but the character of its destructive work is generally misunderstood. The writer just quoted states that the river carries away annually 8 000 acres of bottom land within the limits of the State of Missouri alone. The total acreage of these lands

is about 640 000. If this statement were true, more than the entire area would have been carried away since the voyage of Lewis and Clark, and if the process had been continuous since Columbus discovered America, the river to-day would be flowing in its original channel in the solid rock, 75 to 90 ft. below the present surface. As a matter of fact, there is more soil in the valley to-day than there was at the date of either of these events. Taking an average for a considerable period, none of the bottom land is lost. It has always been slowly rising through accretion. The bank caving is only a transfer from one point of the shore to another. For every dissolving bank there is a nascent bar. Where steamboats ran last year, willows may be growing this, and next year the farmer may be planting his corn. The havoc wrought concerns the individual owner, but not the valley bottom itself. The cruel losses attract attention; the unobtrusive gains do not; but the account always balances itself. The harm done is first to the individual whose possessions are swept away, and second to the community through paralysis of development, depreciation of values, and the holding back of this natural garden spot from becoming what it ought to be. The evil is a very real one, and the writer has long endeavored, though without success, to secure provision in the River and Harbor Bill for its amelioration.* Great as the evil is, however, it is not at all in the nature of an actual loss of land to the valley.

It must be clear from the foregoing that the bottom lands of the Missouri add nothing whatever to the total quantity of sediment that passes out of the mouth of the stream, for these bottoms have been increasing rather than diminishing in quantity. Likewise the Mississippi bottoms contribute nothing to the volume of sediment that is carried into the Gulf of Mexico. It all comes from the uplands, far and near, but principally from the more remote and hilly regions. This load is in the nature of through traffic. The local freight picked up from a caving bank is mostly discharged at the next station. It follows, therefore, that if the banks of these streams were revetted from the Gulf to Pittsburg, the Falls of St. Anthony and the mouth of the Yellowstone, the quantity of sediment passing into the Gulf would not be diminished a particle. Such revetment would never-

* *Transactions*, Am. Soc. C. E., Vol. LIV, p. 336.

theless be of the very highest value, if it could be made to hold, for it would give permanence to the banks, security to riparian property, and would largely prevent bar-building by training the river in a regular channel and relieving it of everything except its through load of sediment.

The bank-caving problem of these valleys is unaffected in any appreciable degree by the influence of forests or cultivation on the water-sheds, and cannot be solved or materially assisted by any practicable changes in these conditions. The problem is strictly a local one, and the remedy must be a local one. Even if it were possible to bring the waters down from the uplands perfectly clear, it is not at all certain that the effect upon the bottom lands would not be injurious rather than beneficial; for then the caving soil, instead of being quickly deposited again, would in part be carried out to sea, and the bottom lands, unless protected, would be gradually eaten away.

In addition to the four main propositions discussed above, a few subordinate features of the question will now be considered.

A feature of the Forestry Service which is generally overlooked is the possible effect of culture upon the bed of humus so much relied upon in these discussions to prove the restraining action of forests upon run-off. Mr. Pinchot, in his statement to the Judiciary Committee, said:

"The effect of a forest on a steep slope is to cover that slope with leaves, rotten and half rotten sticks, and other mechanical obstructions which prevent the water from running below as rapidly as it would otherwise."

It is understood that the forest policy is to keep this litter cleared up as a measure of fire protection, and one frequently sees in articles on forestry, photographs of the typical forest culture in which the ground is thoroughly cleaned up. The result must be to diminish proportionately the retentive action of the forest bed and to increase its liability to erosion. In the light of the foregoing discussion, fire protection is of much greater importance than the retentive effect of the forest bed on the run-off. The remarkable degree to which the forest bed will dry out in prolonged drought, making it one vast tinder-box, supports this conclusion, and is another proof of the extreme desiccating effect of forest growth upon the soil.

It often escapes attention, except with those who are in the woods a great deal, that the water establishes little channels through the débris where the latter is of long accumulation and somewhat permanent in character. Such débris does not in reality offer so great an obstruction to flow as one would suppose, and as would be the case if its condition underwent frequent change.

The statement is constantly met that forests are very efficacious in the protection of river banks from undermining and steep slopes from sliding. The exact reverse is the case. As every river engineer knows, nothing is more disastrous to a river bank on an alluvial stream than heavy trees. This is due partly to their great weight, but in large part to the swaying effect of the wind and the enormous leverage of the long trunks which pry up the ground and facilitate the tendency to undermining. One of the regular policies of river control is to cut down these trees for a distance back from the edge of the bank wherever complications with private ownership do not prevent. Snags and drift-wood in the channels have always been among the most serious obstacles to navigation on streams flowing between forest-covered banks. Likewise where railroad or highway grading cuts the skin of unstable mountain slopes, the presence of large trees immediately above tends powerfully to loosen the ground and cause it to slide; and in such cases it is necessary to cut down the timber. Far better than forest trees on river banks are thick growths of willow, alder, or any of the smaller close-growing shrubs; and on side hill slopes either such shrubbery or a good turf.*

In the current discussion a great deal is made of the fact that mountain slopes are "quick spilling," the deduction being that they therefore are more productive of floods. This is quite contrary to the fact. It is perfectly true that more rain falls on the hills than on the lowlands, that a greater percentage of rainfall runs off from steep than from flat slopes, and that it runs off more rapidly; but it does not follow at all that these conditions produce greater floods. A mountain stream carries off the water within its banks a great deal faster

*The following testimony before the Board of Consulting Engineers, Panama Canal, is to the point (Report, p. 329):

Question by Mr. Welcker: "Mr. Chairman, I would like to ask if Mr. Dauchy thinks that vegetation prevents the sliding?"

Mr. Dauchy: "My experience has been the reverse; I have stopped sliding hills by cutting off the vegetation. The weight of the timber on a sliding slope aids materially to assist the sliding."

Mr. Welcker: "Does not the vegetation diminish it?"

Mr. Dauchy: "If you could get a grass-covered slope it would help to diminish it."

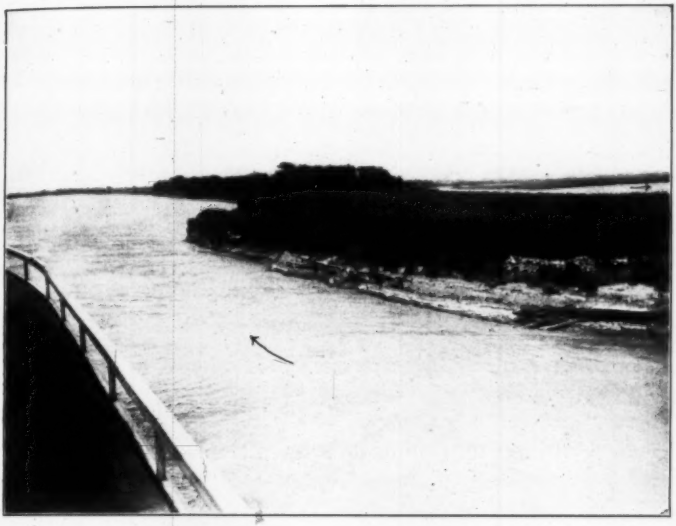


FIG. 1.—CUT-OFF ON MISSOURI RIVER ABOUT TO TAKE PLACE.

FIG. 2.—CREW FELLING TREE FROM RIVER BANK.

and more safely than a similar stream in the lowlands. The banks are almost always stable and the bottoms rocky or composed of heavy gravel or boulders; in fact, floods do less harm on such streams than on any others. In the low land, where the streams have smaller slopes and unstable banks, much smaller run-off produces greater floods and more destruction. Moreover, Nature to a large degree adapts streams to the work required of them. The channels of the tributaries of the Ohio have been carved out through long ages to carry in safety the average flood flow. Area for area of water-shed, their cross-sections are much larger than those of streams in climates of less rainfall. The normal section of the Ohio at Wheeling is over 2 sq. ft. for every square mile of water-shed, while that of the Kaw River at Kansas City is less than $\frac{1}{3}$ sq. ft. per square mile. It is therefore wholly erroneous to conclude that the streams of these mountains are more subject to over-bank freshets than those of the low lands or that the freshets themselves are more destructive. Considering the conditions growing out of settlement, the reverse is unquestionably the case.

There is one other consideration of prime importance in this forestry argument, and that is the fact that no possible development of forestry can increase the present percentage of forest-covered areas. At least as much ground as is now devoted to agricultural purposes must continue to be so used. The utmost admissible expansion of National forests will never require a greater area than is now occupied by forests and second growth or logged-off lands, which, so far as run-off and erosion are concerned, are just as effective as the virgin forest itself, and more effective than will be the groomed forest of the new régime. There may be a shifting of areas devoted to forests, but possible expansion, compared with the present area, is so small that its influence upon the great rivers, even admitting the full force of the forestry argument, would be wholly inappreciable.

The fact just dwelt upon should make us thankful that the forestry theory as to the stream flow is not correct. Whatever the value of forests, we cannot have them everywhere, and by far the greater portions already cleared away must always remain deforested. If this fact of deforestation has brought with it in greater degree than of old the calamities of high and low waters, then, indeed, we are in an unfortunate case. But it has not done so. Nature has decreed no such penalty for the subjugation of the wilderness, and on the whole these

natural visitations are less frequent and less extensive than they were before the white man cut away the forests.

In summarizing below the foregoing argument, the writer would be particularly careful to guard against sweeping assertions in any of his conclusions. He well understands how little the subject is capable of precise demonstration. Snow, for example, does not always fall, even in the open country, under the influence of the wind, or it may fall in a wet condition that keeps it from drifting. Altitude comes in with its lower temperature and modifies the general result. There is a vast difference between a northern and a southern exposure even with the same slope and topographical conditions. Precipitation scarcely ever occurs twice alike on the same water-shed. The combination of flow from tributaries is never the same in any two floods, and there is an endless variety of conditions that must qualify our rules and make us cautious in making claims in a matter of this kind. The writer objects solely to the contrary course pursued by many forestry advocates—to the extreme claims that forests exert a regulating influence upon stream flow in times of great floods or extreme low water in our larger rivers. These claims stand to-day absolutely unproven. The difference between past and present conditions is not great. One influence offsets another with such nicety that the change, if there is any, is hard to find. The "delicate balance" maintained by Nature where Man has not cut away the forests is replaced by other balances equally delicate and efficacious in the drainage of lands, the growing of crops, and the deposition of dew.

In the following seven propositions the writer sums up the arguments presented in the foregoing pages:

(1) The bed of humus and débris that develops under forest cover retains precipitation during the summer season, or moderately dry periods at any time of the year, more effectively than do the soil and crops of deforested areas similarly situated. It acts as a reservoir moderating the run-off from showers and mitigating the severity of freshets, and promotes uniformity of flow at such periods.

(2) The above action fails altogether in periods of prolonged and heavy precipitation, which alone produce great general floods. At such times the forest bed becomes thoroughly saturated, and water falling upon it flows off as readily as from the bare soil. Moreover the forest storage, not being under control, flows out in swollen

streams, and may, and often does, bring the accumulated waters of a series of storms in one part of the water-shed upon those of another which may occur several days later; so that, not only does the forest at such times exert no restraining effect upon floods, but, by virtue of its uncontrolled reservoir action, may actually intensify them.

(3) In periods of extreme summer heat forests operate to diminish the run-off, because they absorb almost completely and give off in evaporation ordinary showers which, in the open country, produce a considerable temporary increase in the streams; and therefore, while small springs and rivulets may dry up more than formerly, this is not true of the larger rivers.

(4) The effect of forests upon the run-off resulting from snow-melting is to concentrate it into brief periods and thereby increase the severity of freshets. This results (*a*) from the prevention of the formation of drifts, and (*b*) from the prevention of snow-melting by sun action in the spring, and the retention of the snow blanket until the arrival of hot weather.

(5) Soil erosion does not result from forest cutting in itself, but from cultivation, using that term in a broad sense. The question of preventing such erosion or soil wash is altogether one of dispensing with cultivation or properly controlling it. The natural growth which always follows the destruction of a forest is fully as effective in preventing erosion, and even in retaining run-off, as the natural forest.

(6) As a general proposition, climate, and particularly precipitation, have not been appreciably modified by the progress of settlement and the consequent clearing of land, and there is no sufficient reason, theoretically, why such a result should ensue.

(7) The percentage of annual run-off to rainfall has been slightly increased by deforestation and cultivation.

If the foregoing propositions are correct they enforce two very important conclusions—one relating to the regulation of our rivers and the other to forestry.

It follows that no aid is to be expected in the control or utilization of our rivers, either for flood prevention, navigation or water power, by any practicable application of forestry. Remember always that it is the extreme of flow, not the medium condition, that controls the cost of river regulation. It is the floods and low waters that measure the cost. Any scheme of control that is not based upon these

is worthless. This proposition need scarcely be urged upon the experienced engineer. For himself he would never place any real reliance upon forestry. Called in consultation, for example, in the problem of protecting the City of Pittsburg from floods, he would be bound to take as his measure of the problem the highest recorded flood on the river with a good factor of safety on that, and then figure out by what methods—artificial reservoirs, levees, raising of grades, or clearing the river channel of artificial obstructions—he would obtain the desired relief. He would not dare, as the physician in the case, to advise his patient that he could dispense with or lessen in any degree the application of the remedies proposed, nor save one dollar of the cost, by anything that might be done in reforesting the water-shed of the rivers themselves.*

In like manner no engineer could honestly advise lowering in height by a single inch the levees of the Mississippi because of any possible application of forestry to the water-shed of that stream. And again he could not advise that forestry development would lessen in any degree the cost of improving the rivers for low-water navigation. Engineers fully understand their responsibility in these matters. But great engineering projects cannot be carried out without money, and the people will not give the money unless convinced of the necessity and wisdom of the plan proposed. So long as there is apparently some easier and simpler plan, some panacea, no matter how nebulous or unproven, that offers a way out without the expenditure of so much cold cash, they will be backward in voting money, and the counsel of the engineer will be of no avail. Hence the complete divorcement of forestry from any connection with river regulation—so far, at least, as its effect upon the cost of such regulation is concerned—will be a distinct and positive gain to the latter.

In the second place, forestry will be left to work out its own salvation without any reference to the rivers. Will not its cause be promoted by this divorcement? At first thought it may seem that thereby one great argument for forestry is lost; but no argument can be of

*Possibly the writer is too positive in this opinion. He finds that, in one case at least, the City of Williamsport, Pa., reputable engineers have advised reforestation of mountain slopes as a protection against floods. The statement of "an eminent authority" was cited with approval to the effect that "four-fifths of the precipitation is detained by the surface of the ground" under forest cover. But here, as in all these assumptions, the rule applies only to the average condition. The point is overlooked that in periods of heavy precipitation the retentive capacity of the forest bed becomes exhausted. If the City of Williamsport is relying upon this advice it is certainly laying up for itself a season of repentance.

value in the long run that is not based upon truth, and the disappointment that is certain to result in the fulfillment of these hopes will do more harm than good. Forestry does not need any such support. It stands on a basis of its own, too broad and too sure to require any extraneous aid. What is this basis? The reply may be given in the beautifully appropriate phrase that occurs in the Act of Congress creating the first of our National Parks, "the benefit and enjoyment of the people." In the matter of benefits, forests are necessary, because they produce the most important material of construction known to Man; even iron cannot be excepted. From the lead pencil to the mast of a ship, from the infant's top to spacious temples and palaces, it enters into nearly every requirement of human existence. A large portion of the structures for human habitation are built of it. The land transportation of the world is closely dependent upon it, for if it were not for the railroad tie scarcely a car could run. It is only when one stops to think a little upon the unlimited adaptability of wood to human needs that its transcendent importance is borne in upon him.

In the matter of enjoyment, no other work of Nature has done more for the uplifting and ennobling of the mind than these "first temples" of God. It requires no argument to enforce this assertion, particularly with him who has been reared in close companionship with the woods. Sad indeed will be the day, if it ever comes, when the people are deprived of this source of healthful pleasure for which no adequate substitute can ever be found.

And yet this supremely important resource in human happiness is strictly limited, and the visible supply is fast disappearing. Statistics fix the date, almost as confidently as an astronomer predicts an eclipse, when the doomsday of its final disappearance will come unless something is done to prevent. Most fortunately, this material, unlike copper or iron or stone, is a vegetable product capable of self-renewal, and the supply can be kept up forever. This is what gives its immense importance to forestry. It requires no dubious support from any other source. It fully justifies the splendid work that the Forestry Service is doing, and demonstrates the wisdom of the far-sighted men who are laying the foundation of our future National forests.

Let us now inquire if it will not be to the advantage of this great work to be absolutely independent of any connection with water

way development. Will it not be better in every way for forestry if it is promoted solely on the basis of producing trees for human use and enjoyment, and not at all for any supposed influence upon flow of streams? Is it really a wise move, so far as forestry is concerned, to single out the rugged and inaccessible mountains as localities where our future supply of timber must come from? The availability of forests to human needs depends very largely upon the situation in which they grow. Few people understand the exceeding importance of this matter. The converting of a forest tree into form for use involves two distinct processes, the conversion of the tree into lumber or other product and its transportation to the place of consumption. The cost of logging operations is immensely increased by the roughness of the ground. In our Western forests, for example, it requires a higher grade of skill, commanding higher wages, to "lay" a tree on a steep hillside than on even ground. The losses from breakage in falling are much higher, and the difficulty and expense of getting the logs out much greater. In fact, the increase of cost runs all the way from $1 to $10 per 1 000, depending upon the situation. *Engineering News* stated the case very forcibly in regard to the Appalachian forests (though it did not have this particular thought in mind), when it said in a recent issue that "the cutting off of forests on the remote mountain slopes has only become possible with the high price of lumber that has prevailed for ten years past." This increase of cost represents the perpetual tax that the public must pay for timber from these regions as compared with that from the lowlands. And a great deal of it can never be gotten out at all. The poet's "gem of purest ray serene" was not more lost to human needs than are tens of thousands of noble trees in the rugged fastnesses of our mountains, east and west. Benefit? To convert them into lumber will cost more than they are worth. Enjoyment? Only the solitary hunter or mountaineer ever sees them. These are not the places to rear up forests for the good of the people.

Consider the question of transportation and take Chicago as being practically on the meridian through the center of population of the country. The rate on fir from the Cascades to Chicago is 55 cents per 100, or $16.50 per 1 000 ft. B.M. The average rate from the Appalachian forests is about 18 cents, or about $9 per 1 000 for green oak. By a proper distribution of our forests, these rates on the average

ought to be brought within 10 cents per 100. In logging and transportation together, the country will tax itself on the average not less than $10 per 1 000 for whatever supply it derives from these mountain forests as compared with what it might receive from forests more favorably located.

If it were not for the erroneous assumption that forests have a regulative effect upon the flow of our navigable rivers, would not the policy in regard to the acquisition of lands for forest reserves be quite different from that now proposed? If Congress were to vote, say, $10 000 000, at the next session to commence the establishment of National forests by purchase, would it not be far better spent in lands where the pine, oak, cherry, and ash used to grow, in locations convenient for access by the people and in every way better adapted to their needs? States, counties or other agencies should be required to meet half the original cost. Even if the total cost to the Government were several times what equal areas in the mountains cost, it would be far more economical in the long run. There is an abundance of land in nearly all the States, suitable for the purpose, that can be had at not excessive cost. In New England, for example, would not the development of forests in the lowlands, where in many places former cultivation has been abandoned, be far better than to buy up the difficult slopes of the White Mountains? Let there be a National forest in every county of the United States where it is practicable to create one. Let its location be carefully chosen so that its product may be manufactured and shipped with the smallest cost to the people, and serving also, not only as a pleasure ground, but as a stimulus to similar work by private agencies.

It will be urged that these mountain lands are worth more for forestry than for agriculture. Very true, but that would not justify their purchase if the same money would produce a better result elsewhere. "Never buy what you do not want because it is cheap." Again, it may be said that here is our only remaining timber supply in the East, and it must be saved. Except in some possible economy by the more judicious cutting under Government control, it is not apparent how a forest tree that has attained its growth is going to render any greater good to humanity by being saved for the next generation than by being cut for this. There is a general sentiment current in these later years that if timber is cut off by private agencies it is wasted;

but does it not find its way into common use just the same? Not as completely, perhaps, but still substantially the same. Take the combination of the Weyerhauser Timber Company, considered entirely apart from its economic and ethical aspects as a great trust or corporation, and solely as a preserver of our forests. With its system of fire control, its policy of holding its timber for high prices, is it not really conserving the timber for future use? To speak of such timber as being "lost" to the people, "wasted," and its acquisition as a "looting of our heritage," is as disingenuous as it is untrue. Will its lumber cost the consumer a cent more per thousand than if it were from a Government reserve? It is a wholly gratuitous assumption that our timber is going to be "wasted" unless it is placed under Government control. The thing of prime importance is to get new forests started. In the 30 to 50 years that our present supply will last, new forests should be brought into existence all over the country. This is far more important than to buy the virgin timber of the Appalachians.

Moreover, it seems now to be considered that the virgin lands have already risen too high in price to be purchased by the Government, and that it is only the second-growth lands that can be economically acquired.* Be that as it may, it is certain that the acquisition of such of these lands as are desirable for the strict purposes of timber production will be greatly facilitated by disabusing the minds of the owners of the impression so diligently fostered of late that the very salvation of the country depends upon their selling out to the Government. Can anyone doubt that the present course will add vastly to the purchase price?

Still another argument that may be urged is that only by linking the forests with the rivers in a way to establish their utility in maintaining navigation can the constitutional objection to the acquisition of these lands be overcome. But does this apply to mountain forests more than to any others? It is incontestably true that whatever restraining effect forests have upon run-off is greater upon the lowlands than upon steep mountain sides. This legal feature of the question will be referred to farther on.

*Report of Secretary of Agriculture on Southern Appalachian and White Mountain water-shed, December, 1907, pp. 8, 30, 35.

Reservoirs in Their Relation to Stream Flow.

Under this heading artificial reservoirs alone are included. Natural reservoirs of various kinds exist nearly everywhere, and exert a profound influence upon stream flow. The ground is the most important of these, absorbing on the average probably one-third of the total rainfall. Natural lakes are great regulators, the St. Lawrence system being the most perfect example. Forests are effective reservoirs at certain seasons. Swamps and low-lying grounds along river courses, like the great flood basins of the Sacramento and the Mississippi, are, in their natural state, enormous reservoirs which greatly reduce the flood flow of the river channels. Snow-drifts, particularly the great drifts of the mountains, are splendid reservoirs. The streams themselves have immense storage capacity; for example, the Mississippi within levees stores at least 2 000 billion cu. ft. of water from Cairo to the Gulf, between extreme high- and low-water stages. All these reservoirs and many of less importance are ever active in regulating the flow of streams. Without them, precipitation would flow off as fast as it arrives, and our greatest floods would be magnified many times.

Here we are considering only those reservoirs constructed by Man to supplement and extend the regulating effect of Nature's reservoirs. If the conclusions reached in the first section of this paper are correct, forests cannot be relied upon in any degree to help solve the problems of high and low water. Present conditions must be met by purely artificial means, since Man has so far discovered no way of controlling the climatic conditions which govern precipitation. He cannot "stay the bottles of heaven" in times of flood, nor open them in seasons of drought. He must take the water after it reaches the earth, and deal with it the best he can.

The artificial reservoir is intended to attack this problem at its source. It catches and holds back the water in the near vicinity of its deposition, instead of waiting until it gathers into the rivers, and then building huge bulwarks to contain it there in times of flood. It saves the stored-up supply and gives it out in the low-water season, thereby helping navigation, instead of dredging and otherwise treating the watercourses to increase the low-water depth. It corrects one of the greatest deficiencies of Nature by abolishing inequalities of stream flow and converting waste into utility. Theoretically, it is

the perfect plan. It has always appealed to the imagination of layman and professional alike. It has often been resorted to, and the number of reservoirs in the world is very great and constantly increasing. Hitherto they have been mainly used for power, municipal supply, irrigation, and for navigation in canals. In very few instances have they been applied to improve the navigation of large natural watercourses, and in none, so far as the author is aware, for the exclusive purpose of preventing floods.

The question arises, why are they not regularly applied to these last-mentioned purposes? The answer may at once be given that in the general case the cost is greater than the benefits to be received. This element of cost arises mainly from the absence of good sites (including dam sites as well as holding basins) and also, to considerable extent, from an interference with the purely artificial conditions growing out of the settlement of the country.

The best reservoir site is a natural lake. Such a site is already covered with water, and original conditions are not materially changed. Evaporation is not much increased by the necessary enlargement. Smaller and safer dams accomplish a given storage than for the average dry site. The question of public health involved in uncovering large areas for reservoir beds in the heated portion of the year is less serious. Everything makes these sites the most advantageous that can be found, and it may be laid down as a rule that the public good requires the utilization of every such site to the fullest possible extent.*

Except in a few cases, dry sites are deficient in these advantages. Greater areas of land have to be condemned, and larger and costlier dams are required, with vastly greater danger in case of accident. Really good sites are not as abundant as one might wish, and the

*An interesting feature of these natural reservoirs may be noted. A natural lake, wholly uncontrolled at its outlet, may have a more effective control of the outflow than an artificial reservoir of equal superficial area when full, though of far greater capacity between high and low water. The outflow from a lake can be increased only by storing simultaneously a quantity of water measured by a rise in the surface equal to that in the outlet necessary to give the increased flow. But if the artificial reservoir has reached the limit of its allowable filling, the outflow must be made equal to the inflow. If this limit is reached before or at the time of maximum run-off, then a quantity equal to this run-off must be let out of the reservoir. This contingency can never happen in a natural lake. The turning point where outflow and inflow balance each other is always after the crest of the flood has passed—in fact at the time when the diminishing inflow and increasing outflow balance each other and the lake ceases to rise. In the case of the Yellowstone Lake (140 sq. miles), for example, this rise, in average seasons of snow-melting, continues from 10 days to 3 weeks after the inflow has reached its maximum, and surrounding streams have subsided materially before the Yellowstone River (at the lake outlet) ceases to rise.

problem of developing storage on such sites is beset with difficulties of many kinds that greatly increase the cost.

In 1897 the writer made a careful study of this question of flood control by means of reservoirs in connection with an official investigation of the advisability of building reservoirs in the arid regions. His view of the difficulties in the way of any general application of such a system is quite fully stated in his report,* and the following extracts are directly in point:

"It is the cost, not the physical difficulties, which stands in the way. It may be stated that as a general rule a sufficient amount of storage can be artificially created in the valley of any stream to rob its floods of their destructive character; but it is equally true that the benefits to be gained will not ordinarily justify the cost. The reason for this is plain. Floods are only occasional calamities at worst. Probably on the majority of streams destructive floods do not occur, on the average, oftener than once in five years. Every reservoir built for the purpose of flood protection alone would mean the dedication of so much land to a condition of permanent overflow in order that three or four times as much might be redeemed from occasional overflow. One acre permanently inundated to rescue three or four acres from inundation of a few weeks once in three or four years, and this at a great cost, could not be considered a wise proceeding, no matter how practicable it might be from engineering considerations alone. The cost, coupled with the loss of so much land to industrial uses, would be far greater than that of levees or other methods of flood protection. * * * The construction of reservoirs for flood protection is not, therefore, to be expected, except where the reservoirs are to serve some other purpose as well."

The above conclusions are still as applicable as they were when written. The subject has been given renewed prominence quite recently in connection with the Ohio River floods, but, before considering this particular application, attention will be given to certain reservoir systems that have been proposed elsewhere, and particularly to one already built and put in operation by the Government and which will be referred to frequently in the following pages. This is the system at the head-waters of the Mississippi—the largest artificial reservoir system in the world.

The project of converting the more important of the numerous lakes around the sources of the Mississippi and its tributaries into

*House Doc., No. 141, 55th Cong., 2d Sess., p. 46.

storage reservoirs as an aid to navigation was originally proposed by General G. K. Warren, and was first put into definite shape by the late Colonel F. U. Farquhar, M. Am. Soc. C. E., of the Corps of Engineers. The plan then embraced a large number of lakes in Minnesota and Wisconsin, but only five sites have actually been improved. The dams were first built of timber cribs, but have recently been rebuilt in concrete, as shown on Plate XLII. The combined storage is about 93 billion cu. ft. It is about twice the mean annual run-off from the water-shed, and the system is probably the only one, except the Great Lakes, which equalizes periodic as well as annual fluctuations of flow. That is, it carries over the surplus from wet years to help out in dry years, and its utility is, therefore, of the most comprehensive character. The cost of the five reservoirs is remarkably low, although it is not now possible to tell the exact cost of the present structures on account of the mixture of old and new work; but it probably does not exceed $750 000, including a lock in the Sandy Lake Dam. This is only $8 per 1 000 000 cu. ft., or 35 cents per acre-foot on the basis of total capacity. It would be about twice this on the basis of the mean annual run-off from the water-sheds.

A large portion of the original project has been abandoned because public sentiment did not support its continuance. The writer has always regretted this backward step, as he believes in developing to the fullest extent the exceptional opportunities here offered for the storage of water. The available reservoir sites which could be cheaply improved in Minnesota and Wisconsin are sufficient to control absolutely the floods of the Mississippi within the danger line, for a long distance below St. Paul, and to improve the navigation of the upper river very materially, while their value for industrial purposes is almost beyond estimate.

In spite of the great and obvious advantages of this system, it has not yet received the popular approval that might be expected of it. In fact, about three years ago, there arose a widespread sentiment in the community around the reservoirs that the system was, on the whole, injurious, that its disadvantages far offset its advantages, and a strong movement was organized to have it abolished altogether. For the purpose of investigating this matter, a Board of Engineers was appointed, of which the writer was a member. The Board found that there was a general belief among the people below the dams that

DIAGRAM SHOWING EFFECT OF UPPER MISSISSIPPI RESERVOIRS ON FLOOD SITUATION AT AITKIN, MINN., 1905.

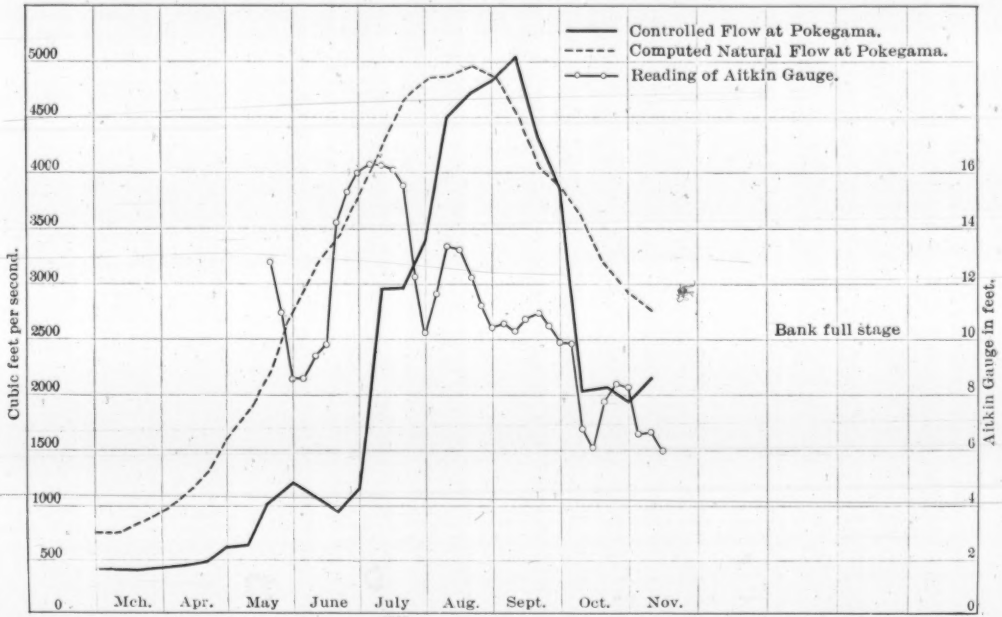


FIG. 2.

they actually increased the floods, while the people above complained bitterly of the back waters caused, throughout that low country, by filling the reservoirs so full. The water-powers immediately below the dams complained that they were not getting even the normal flow of the stream, which was the case. Navigation interests below St. Paul have always been lukewarm in regard to the beneficial effects of the reservoirs, and the Board was able to find only one steamboat captain who would make a positive statement that the boating interests derived any particular benefit from them.

Some curious results developed in this investigation. It was found that, great as the reservoirs are, conditions may arise in times of excessive precipitation that will compel them to discharge a greater quantity of water than would flow from the lakes in their natural condition. That is, they might actually operate to increase the floods if they should fill to their limit during a period of excessive precipitation. This very contingency nearly happened in the season of 1905, as may be seen on the curve (Fig. 2) illustrating the effect of the reservoirs on the flood situation at Aitkin, Minn., about 130 miles below. On Fig. 3 is shown a comparison of the natural and regulated flow of the Mississippi below the three upper reservoirs, the latter being operated in the interest of navigation alone. These curves show very clearly that the natural flow of the river was more uniform than is the regulated flow.

In like manner, during the period of lowest water, viz., in midwinter, the reservoir gates are closed down to about 400 cu. ft. per sec., and the great water-powers, like those at the Falls of St. Anthony, are even worse off than in a state of Nature; but this drawback is not as great as might be thought because the powers are able to utilize most of the storage when it comes during the period of navigation.

Such are some of the complications and drawbacks which are encountered in this reservoir system and which would surely be met in a system built up under less favorable natural conditions.

Nevertheless the Board found that the system was in itself a very great benefit and that the lack of appreciation of its advantages was for the most part due to ignorance of what they actually were. At the public hearing the opposition fell to pieces by the mere force of a better understanding, and it is safe to say that the system will

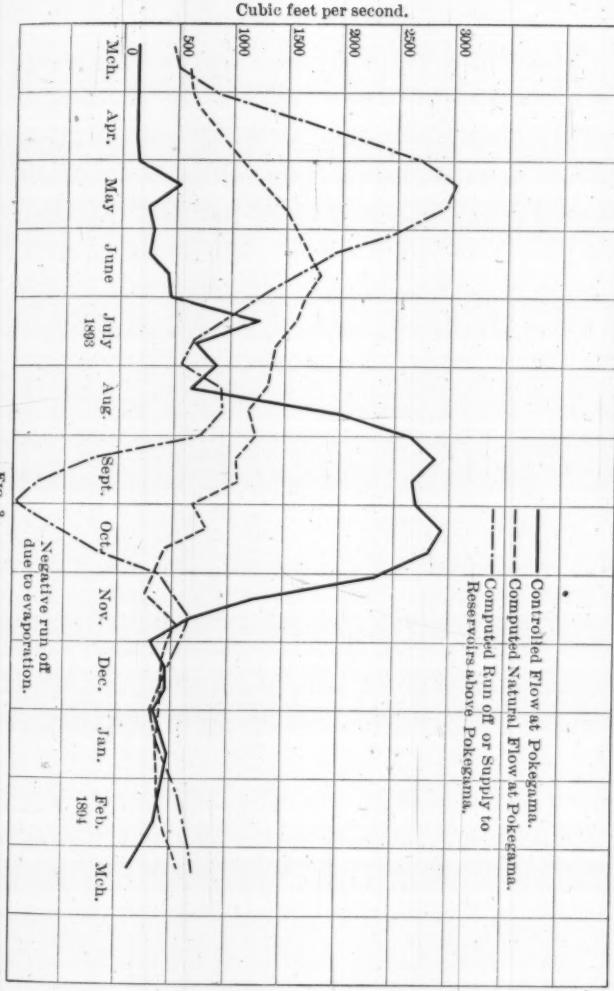


DIAGRAM SHOWING COMPARISON BETWEEN NATURAL AND CONTROLLED FLOW OF MISSISSIPPI RIVER BELOW THREE UPPER RESERVOIRS.

FIG. 8.

never be abandoned, but will be extended along the lines of the original project.*

The U. S. Geological Survey has recently proposed quite an extensive reservoir system for the Sacramento Basin, similar in principle, though smaller in extent, to that of the proposed Ohio system. The flood problem of the Sacramento River is the most difficult in the United States in proportion to its magnitude. In fact it seems as if it will prove impossible to convey the extreme floods of that river to the sea without extensive overflow of the bottom lands along its course. The proposition to control the floods to some extent by means of reservoirs was elaborately set forth in the paper by Messrs. Clapp, Murphy, and Martin, previously referred to. The subject had already been considered by the Commission of Engineers appointed by the State of California in 1904 to devise a plan of flood relief. The Commission reported that, while any help from such a source must, of course, be welcome in solving the problem, it was very doubtful if such aid would be of sufficient importance to justify giving it much weight.† In discussing the paper above referred to, the writer stated that, while he had never visited the sites in question, it was his opinion that, as to most of them, it would not be possible to realize more than one-fourth to one-third of the benefits claimed, and he based his opinion on the published records of the flood of 1907, which was the greatest in the history of the river. George L. Dillman, M. Am. Soc. C. E., in discussing the paper, flatly pronounced the whole scheme impracticable, and gave his reasons in detail for this conclusion.‡ Among them he cited in one case the great value of the lands to be flooded by the reservoirs, which he claimed were altogether more important for agriculture than for any diminution of flooding which the storage might cause in the valley below. In another case he cited the difficulty, which always suggests itself to an engineer in considering the subject, of timing the operations of the reservoirs so as to combine their effects to the best advantage, and particularly in keeping them empty in periods of prolonged precipitation, so that their capacity may be available at the critical moment. Other obstacles were pointed out, and the whole discussion presents another instance

*The report of this Board contains exhaustive data upon the system and its operation. It may be seen in the annual report of the Chief of Engineers for 1906, p. 1443 (Appendix AA, published separately in pamphlet form).

†Report, Commissioner of Public Works, State of California, for 1905.

‡*Transactions*, Am. Soc. C. E., Vol. LXI, p. 357.

of the practical difficulties that stand in the way of any comprehensive reservoir scheme for controlling floods.

In 1903 the great flood of the Kaw River brought up the reservoir question again. Ex-Senator Burton, of Kansas, advocated the plan very urgently, stating in a speech at Kansas City that he "would have tens of thousands of reservoirs beginning at the head-waters of the stream and coming right down." A Board of Engineer Officers was appointed to investigate the practicability of providing against future disasters such as this flood had caused. The reservoir idea had made so deep an impression upon the public mind that a specific consideration of that feature of the problem was requested. In its report* the Board found adversely to the scheme on the ground that its great cost, conservatively estimated at $11 000 000, and the annual loss from the withdrawal of the necessary lands from occupancy, conservatively estimated at nearly $600 000, would not be justified on the ground of flood protection alone. Owing to the character of the country, this last consideration was particularly strong. The only real justification of so extensive a system in a country so largely devoted to agriculture would be its use in irrigation and power, and, if it became necessary for these purposes, doubtless a portion of it would be built.

The most elaborate study of this subject ever undertaken until very recently was made by the French Government, to determine whether reservoirs could be utilized to prevent the recurrence of such great disasters as the floods of 1856 in the valleys of the Rhone and other streams. A full résumé of these studies is given in the writer's report already referred to on Reservoir Sites in the Arid Regions. The conclusion was the same that has been reached in every similar investigation. An interesting feature of the system then considered was that the reservoirs were to have sluices permanently open so that it would not be possible to close them entirely. They would operate, it was expected, to hold back a definite percentage of flood discharge—enough to keep the floods below the dams within safe limits. They would thus act automatically, just as forests are supposed to do. This was all right so far as the individual tributaries were concerned, but it was found, when the possible effect upon tributary combination in the main stream was considered, that, by holding back earlier portions of freshets and prolonging their run-

*Senate Doc. 160, 58th Cong., 2d Session, pp. 14-17.

off, they might actually swell the combination in the lower courses of the main stream.

Similar studies have frequently been made in all the principal countries of Europe, and in none of them, so far as the writer is aware, has such a project on a large scale ever been undertaken or even favorably considered.

Coming now to the Ohio River, the immense importance of that stream as a factor in the floods of the Mississippi makes the regulation of its flow a matter of greater moment than that of any other stream. The project of controlling the run-off of its water-shed by means of reservoirs was urged very forcibly more than 60 years ago by Colonel Charles Ellet. The subject has often been considered since, both in private and official investigations. The conclusion has invariably been that, great as the benefits of such a system would be, if in existence, the cost of bringing it into existence would be out of all proportion to such benefits.

The scheme has recently been revived in a more attractive form, with data not hitherto available, and at a time when a period of heavy floods and much loss therefrom has turned public attention strongly to the subject. Moreover, it comes supported by a comparatively new element in its favor—the vast expansion of water-power development made possible by the electric transmission of energy. The new presentation of the project is by M. O. Leighton, Assoc. M. Am. Soc. C. E., Chief Hydrographer, U. S. Geological Survey, and is understood to bear the approval of both the Interior and Agricultural Departments.* Mr. Leighton does not claim that his presentation is at all final or complete, but is rather a "statement of possibilities" which he believes are sufficiently promising to justify the Government in giving the scheme thorough investigation before further extensive steps are taken on present lines in the matter of flood control and channel improvement in the main rivers of the basin. Although an estimate of cost is submitted and certain conclusions are based thereon, it is stated that the data are too meager to give much confidence therein. Subject to these qualifications, the system, as set forth in Mr. Leighton's paper, embraces reservoirs on nearly all the tributaries

*The writer has seen the description of the proposed system only as published in *Engineering News*, May 7th, 1908. He has had some correspondence with Mr. Leighton, and is under great obligation to him for a complete set of topographic sheets showing the various reservoir sites.

of the Ohio; the total cost is estimated at $125 000 000; the income from resulting water-power at $20 per horse-power, and a certain computed lowering of flood heights on the Ohio and Mississippi Rivers, and a corresponding increase in low stages, are given. The full details of the scheme are set forth in quite elaborate form. So far as the present criticism is concerned, the practicability of finding the necessary sites will be accepted, and only the estimate of costs and revenues, and the deductions as to benefits will be called into question.

In their effect upon floods, admitting that all the reservoirs proposed can be built, the result must fall short of the claims put forth. If built at all, they must be built, as will be shown later, primarily for power development. Now it will never be possible, until Science can forecast the weather more perfectly than it is yet able to do, to regulate reservoirs for the maximum benefit of both purposes. This consideration is sometimes made light of, but nevertheless it is one of real importance. For industrial purposes the reservoirs should be full before the rainy season ends; for flood protection they should be so far empty that they may be able to hold back any flood-producing storm that is likely to come. While, doubtless, in a majority of years, a middle course could be pursued that would not involve much risk on the flood side of the question nor much loss on the power side, yet there would surely come exceptional seasons—the seasons of flood-producing rains or the seasons of great drought—when the reservoirs would be caught too full on the one hand or too empty on the other. Their full calculated capacity would not then be available for either purpose, and it is difficult to conclude that this would not happen frequently. In particular, if the reservoirs are really operated to prevent floods, it must often happen that dry weather will find them only partially filled, and that their full capacity will not be available either for power or navigation. This would not apply, of course, to a reservoir great enough to store all the run-off from its water-shed in the greatest known flood, unless considerable storage were left over from previous years—as is often done in the Upper Mississippi reservoirs. Mr. Leighton's estimates are based upon the mean discharge of the streams, which is, of course, greatly exceeded, possibly doubled, in very wet years. In any case it would seem to be necessary to hold ample capacity in the reservoirs as late as the end of March each year to provide for possible emergencies; but if

this is done there will be many years when the reservoirs will not fill.

An important consideration in the use of the reservoirs for flood control is that of a proper combination of their outflow. To any one who will try to figure out how this can be accomplished over a water-shed of such vast extent, with storms arriving at different times in the various portions, with no way of telling when, where, or with what intensity they will arrive, with the varying distances of the different reservoirs from those points where flood control is particularly important, the problem seems almost impossible—that is, impossible to realize the full effect based upon the aggregate capacity of the system. It is understood that Mr. Leighton has endeavored to do this, but it would be interesting to see the application to some of the great floods that might be designated. For example, in the flood of 1907, which reached its maximum at Cincinnati and Pittsburg about the same time, no amount of holding back of the storm water on the Upper Ohio at that time would have helped the situation at Cincinnati at all.

Another important consideration in the effect of these reservoirs, as they would have to be operated to prevent floods, is the great change that takes place in a flood wave as it propagates itself down stream. The writer is unable to tell from Mr. Leighton's paper to what extent he has considered it. The paper itself seems to indicate that the discharge held back by a particular reservoir produces a corresponding volumetric effect (not gauge effect, of course) at all points below, after making a due allowance of time for the transmission of the wave. This would be an erroneous conclusion. For example, a wave that might rise at Pittsburg from 100 000 cu. ft. per sec. to 150 000 a day later and to 200 000 the next day, and then fall at a corresponding rate, would not at any point below produce a maximum increase of 100 000 sec-ft.; and the farther away the point considered, the less would be the increase. At Cairo, nearly 1 000 miles below, the same wave would take a much longer time in passing, probably not less than a week, and the maximum increase would probably not be more than 25 000 sec-ft. This is merely a general illustration, for exact data on the subject are not available. The problem is of such complexity that nothing but the results of long experience could establish a rule as to what might be expected in any given case; but

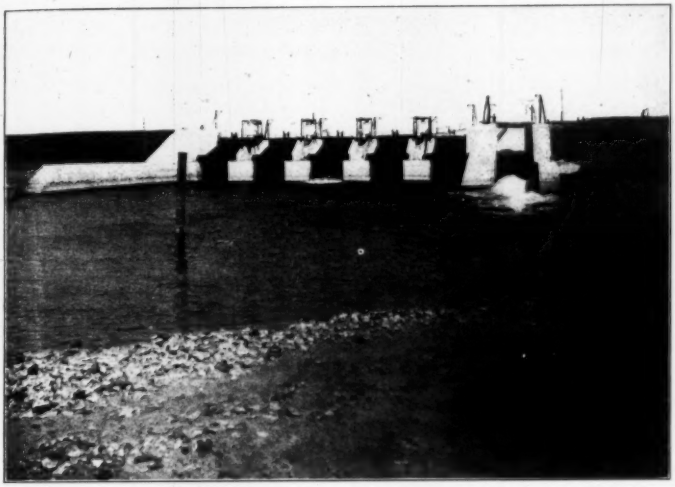


FIG. 1.—LAKE WINNIBIGOSHISH DAM.

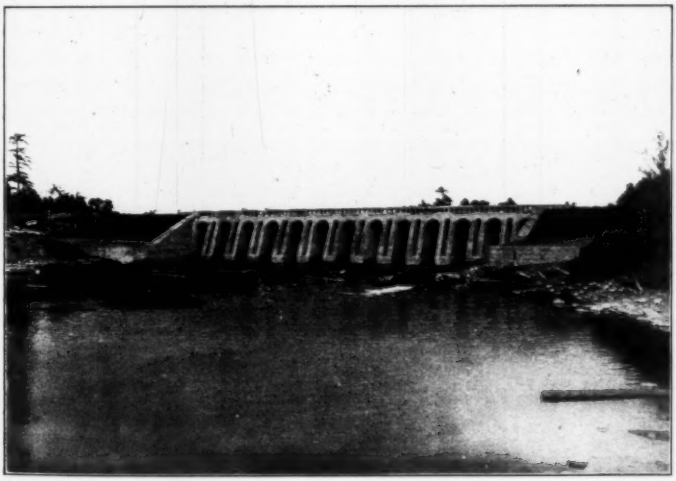


FIG. 2.—PINE RIVER DAM.

it can be stated with certainty that the diminution of discharge at any considerable distance below the reservoirs for a given time would never be as great as the amount held back by the reservoirs in the same length of time, and that, the quicker and the higher the flood, the smaller the relative effect at all points below. It is only when such wave elimination merges into a constant quantity, continuing for a considerable time, that the full effect of a reservoir would be experienced at any point below. This, in fact, is what would actually happen in the contrary case of the low-water season when the reservoir discharge is kept up for a long time.

Still another feature in the high-water effect of such reservoirs is the demand for water for power at all times. If there should ever result any really general use for all this water, as is predicted, then the consumption for power would make a considerable river in itself. Now this much cannot be shut off in any case. Street cars and shops must run and houses must be lighted whether the flood is ruining the lowlands or not. An example of this occurred in 1905 on the Upper Mississippi where the outflow from the upper dams was cut down to a minimum to reduce the flood in the valley at Aitkin, which was then being overflowed by the river. The mill at Grand Rapids, just below the reservoirs, made a strenuous protest, and even threatened legal proceedings to compel the release of the full normal flow of the river.

Considering all the foregoing features of the operation of the proposed system, even if every reservoir were built with the full, estimated capacity, it would be extremely fortunate if 75% of the predicted results, either in flood protection or in aid of navigation, could be realized.

It is in the matter of cost, however, that the weak point of Mr. Leighton's system appears. Judged by any reasonable standard, his estimates are hopelessly wide of the mark. The method itself of getting at a basis of cost is inadmissible. For example, in determining a unit of cost for that class of reservoirs which embrace the greater portion of the total storage, the figures for nine reservoirs are taken, counting as one the whole Upper Mississippi system. Only the Mississippi system has been built; two others are under construction and six are merely projected. In accordance with almost universal experience, and especially in view of the great advance in prices of

all kinds since these estimates were prepared, it must be expected that these works, if ever built, will cost from 25 to 50% more than the estimates. Three of the projected dams are of the relatively cheap rock-fill construction, which would be inapplicable to most of the Ohio dams from considerations of safety.

The controlling element, however, in the unit estimate, is the Mississippi system, whose capacity is nearly one-third of the whole group considered and whose unit cost is only about one-seventh of the average cost of the others. The use of the Mississippi reservoirs in any way as a basis of estimate for the Ohio system is wholly inadmissible because of the dissimilarity of sites. The Ohio sites, with one exception, are dry sites—totally different from the lakes of Minnesota. Even the latter reservoirs could not now be built for three times what they have actually cost the Government. The flowage lands embraced about 80 000 acres, which were nearly all reserved while yet belonging to the Government. A few recent purchases of additional lands found necessary, and the experience now being met in acquiring the flowage rights for a reservoir at Gull Lake, show that, if these lands were to be bought to-day, they would cost from $10 to $25 per acre. The right of way alone would now cost twice as much as the dams.

Compare any one of these structures—Leech Lake, for example—with a representative masonry dam like the Cheesman Dam on the South Fork of the South Platte River above Denver, Colo. The writer is familiar with both sites, and once submitted a plan and estimate for a structure on the Cheesman site almost exactly like the one built. Lake Cheesman is a more favorable site than most of those on the Ohio system, for, although its capacity is not as great as some, the dam site is exceptionally advantageous, one of the most perfect in Nature—a very narrow gorge in solid granite, with a natural spillway already provided. In several of the Ohio sites, entire towns will have to be removed, important railroads will have to be re-located, a few mineral properties will be destroyed, and, in nearly all, road systems will be seriously disarranged. None of these conditions were encountered to anything like the same extent in the Cheesman site. Undoubtedly its unit cost, which is estimated at about $250 per 1 000 000 cu. ft., was as low as can be possibly realized on the Ohio system as a whole. Compare this with less than $5 for Leech Lake or $8 for the whole Mississippi system!

FIG. 1.—LEECH LAKE DAM.

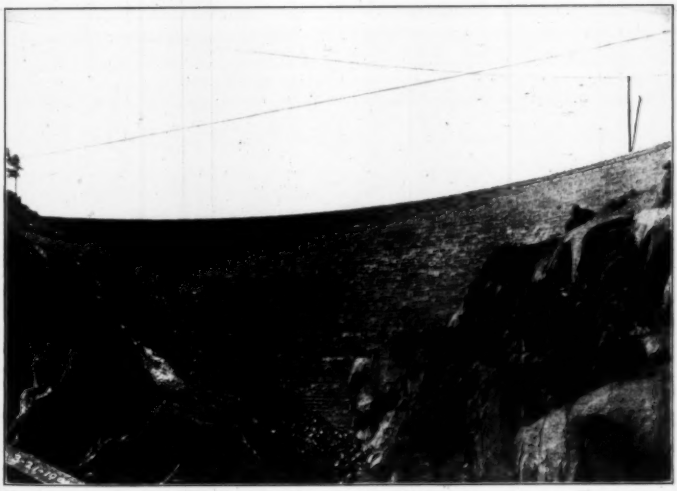


FIG. 2.—LAKE CHEESMAN DAM.

A recent example of projected storage is that presented by the late George Rafter, M. Am. Soc. C. E., for the Genesee River near Portage, N. Y. Owing to the moderate height of dam (apparently less than 150 ft.) and the large capacity of reservoir (15 billion cu. ft.), this is believed to compare favorably as to unit cost with the Ohio system. The estimate was $216 per 1 000 000 cu. ft. If it were to be built under the present conditions of the market, it would doubtless cost $250. It is understood that later investigations have shown that Mr. Rafter's estimate is only one-half large enough.

In 1895 the writer made an extensive examination of storage possibilities in Ohio, near the divide between Lake Erie and the Ohio River, for the purpose of providing a water supply for certain projected canals. He prepared estimates for two sites on the head-waters of the Cuyahoga, for one site at the head of the Scioto, and for one at the head of the Great Miami. The estimates were based upon actual surveys, and are given in detail in the report upon the subject.* The type of construction was not expensive. The total capacity was 11 000 million cu. ft. and the unit cost $300. To-day it would be at least $350.

Most of the proposed sites for the Ohio reservoirs are not advantageous sites. The topography of the country is unfavorable. The sites are not compact basins, like those occupied by lakes or ponds or mountain meadows, but are, for the most part, trunk valleys with numerous tributaries, nearly all of them quite narrow. They may be roughly compared to the form of the hand with the fingers outspread, the dam occupying the position of the wrist. The ends of the fingers are frequently many miles from each other and from the dam. Numerous villages occupy the valleys. The road systems of the local communities traverse them. The disadvantage that will result to public travel, by forcing it out of these natural routes over the hills and around the ends of the fingers, will be very great. The lands lying between the fingers, in some instances, will be so far cut off from convenient access that their value will be much impaired, and damages will have to be paid on that account. In several instances the necessary changes in railroad alignment in the hilly country will be extremely costly, if not impracticable. A great many cemeteries will have to be removed, which means, not only the cost of removal, but

*House Doc. 278, 54th Cong., 1st Sess., pp. 78, 83, 86.

extensive purchase of lands outside. Such drawbacks are, of course, encountered in all similar work, but they are excessive in these sites. They are mentioned solely from their relation to the question of cost. No one can examine the maps of these sites and not be convinced that the cost of right of way and damages alone will considerably exceed Mr. Leighton's estimate of the entire cost of the system.

An element affecting cost is that of safety. Owing to the situation of many of these proposed reservoirs, the results of failure of the dams would be so appalling that no chances can be taken. The structures can be made safe, of course (except against earthquakes), but it will cost money. Nothing short of the highest type of construction —masonry for all the larger dams—can be considered. Mr. Leighton has cited certain dams upon the integrity of which great interests depend as evidence of the confidence of engineers in these structures, but if he will apply their costs, particularly those of important structures in Europe, to his proposed system, the money value of safety will mount up to a prodigious figure.*

A feature of this question of safety often overlooked is the depreciation of the market value of property, due to its location below a dam where failure of the dam would mean a disaster of great magnitude. However safe the structure may be, many people would not purchase property below it, and its market would be correspondingly diminished. While such loss can hardly be made a subject for damages, it is a real loss to the owners.

These reservoirs being built for flood protection, the sluices must be very large, so that at times they can be discharged practically as fast as the water runs in. This will be necessary during periods of prolonged precipitation in order to keep the reservoirs from filling too full before the danger is past. This detail of construction will add largely to the cost.

*The recent failure of the Hauser Lake Dam on the Missouri River, near Helena, Mont., is a good illustration of how the unexpected may happen. Here was a dam built of steel and concrete, two materials whose properties are thoroughly understood. The case was one which "ordinary engineering" might be expected to handle successfully. The public had reason to feel confidence in the structure. Yet "it fell and great was the fall thereof," not only in the total wreckage of the dam, but in the losses caused along the valley below.

The accident affords also another illustration of the omnivorous claims put forward in these days in the supposed interests of forestry. The disaster was promptly cited as an example of the havoc wrought by floods in a country without forests. The normal flood discharge of the Missouri at this point is 20 000 cu. ft. per sec.; for 1907, it was 26 000 cu. ft.; the maximum on record is about 50 000 cu. ft. At the time of the accident the discharge was about 7 000 cu. ft. per sec.

Taking everything into consideration on the most liberal basis, it is evident that this system cannot be built for less than $250 per 1 000 000 cu. ft. The probable increase in the value of property to be condemned before the system could be built, and the present scale of prices of labor and material, make this figure a minimum. This would swell the cost of the whole system to more than four times Mr. Leighton's estimate, or over half a billion dollars.*

This is not all, however. It appears that the complete development of the reservoir system as proposed will take from industrial use probably 1 500 000 acres of land, including the lands actually overflowed, the margins subject to damages, and sites for the dams and various structures appurtenant thereto. These lands will be in large part, by the very fact that they lie in valleys suitable for storage grounds, the best lands in the localities. Sooner or later they are bound to come into agricultural use, and with proper cultivation their annual net revenue value will be at least $5 per acre. If utilized for forest culture, they ought to yield 500 ft. B.M. of lumber and 1 cord of wood annually per acre. The value of the land for this purpose ought to be as great as the figures just given. It thus appears that the occupancy of these lands for reservoir purposes will take from the community an annual product of at least $7 500 000 worth, and probably more.

The reservoirs will store about 2 150 billion cu. ft. of water. Assume that this can all be utilized for water-power, with the average head of 200 ft., giving theoretically about 1 600 000 h.p. per year, or 1 280 000 h.p. at 80% efficiency. At $5 per horse-power (the basis for this figure will presently be considered), the revenue from water-power will be $6 400 000, which falls short of the loss resulting from withholding the sites from productive use.†

Viewed in the light of the foregoing exposition, the weakness of the reservoir scheme, as a measure of flood control or for improving navigation, is at once apparent. The question is: Will the ends justify

*Recent examinations of certain sites, embracing nearly 70% of the proposed Monongahela storage, indicate that the whole Ohio system will cost at least a billion dollars, and possibly a billion and a half.

†The sanitary feature has not been considered, although it is one of some importance. The laying bare of large areas of reservoir bottoms in the heated portion of the year, is objectionable, but it is not a matter affecting the element of cost. Neither is much stress here laid upon the danger to the reservoirs from silting up. This is not a region of heavy silt movement. In most of the reservoirs, the process will be very slow, and we may safely leave to distant generations the task of dealing with this problem whenever it reaches an acute stage.

the means? If the ends sought could be attained in no other way, possibly they might; but they can be, and for a small fraction of the reservoir cost. Consider the estimate, already given, of $500 000 000. Take $40 000 000 and reinforce the entire levee system of the Mississippi. That will make it impregnable—as safe as any of the proposed reservoir dams. Take $60 000 000 and revet the banks of the Mississippi wherever necessary from Cairo to the Gulf.* The reservoir project does not touch this important matter at all. Devote whatever sum is necessary to the protection of the bottom lands of the Ohio basin. Give Cincinnati and Pittsburg each $10 000 000 to assist in local changes necessary for complete flood protection. Devote a sum to navigation such as our engineers have never dared dream of, and the Government will still save more than Mr. Leighton's estimate of the whole cost of the reservoir system. The more closely this reservoir proposition is scrutinized, as a scheme for flood prevention, the more impracticable it appears. It is only a trade-off at best. It is giving up to perpetual overflow valuable lands to save others from occasional and even rare overflow for short periods. Now if, at less cost, these lowlands can be better protected by other means, thus leaving both the valley lands and reservoir sites open to productive use, how much better it will be!

If the writer were to venture a criticism on Mr. Leighton's attitude in this matter, it would be that he has not fully appreciated his responsibility in bringing forward again this old proposition without fuller consideration of its organic defects. This is well illustrated in the opening paragraph of his paper, in which he says:

"This report will be confined to a statement of possibilities. There will be no attempt to prescribe methods for treatment of each local modifying condition that will be encountered in the prosecution of the plan here proposed. Such features are merely collateral, and their proper disposition is a matter of ordinary engineering."

This is a complete reversal of his obligation in the matter. The "possibilities" of reservoir control have long been recognized. The logic of the plan is well understood. It has always appealed to the popular mind. In particular, reservoir control of the Ohio floods has been advocated for more than 60 years, and its possibilities have often been investigated. The plan has been uniformly rejected on

*Report, Mississippi River Commission, 1896, p. 3457.

one ground, viz., that as a scheme for flood control and navigation improvement its benefits would not justify its cost. It is, therefore, incumbent upon whoever revives the scheme to come well fortified upon this particular feature. He must give some study to the treatment of "local modifying conditions." It makes a difference whether he can go to a great natural lake like Winnibigoshish and store 40 billion cu. ft. of water for a mere trifle, or whether he must evict whole villages, disturb railroads and highways, absorb valuable lands and possibly subject communities to serious risk. These are the questions upon which the success or failure of the scheme depends. Yet Mr. Leighton brushes them aside, as it were, with a wave of the hand, as "merely collateral" features, matters of "ordinary engineering" only. Here is the weak point of his project. Weighed in the balance of practical accomplishment, either for flood control or navigation, it will be found utterly wanting, and the development of the system, as has always been held, will have to be based primarily and mainly on its value for industrial use. For the same reasons that the development of a great reservoir system in the Far West is justified by its industrial value—its use for irrigation—so a reservoir system for the Ohio, or any other rivers, except in a few unusual cases, must depend primarily upon its industrial value—the development of power.

In pursuing his criticism further, the writer would not be understood to be "knocking," as current slang goes, the feature of the reservoir system just mentioned, because, in his judgment, there is no one thing in the present movement for the conservation of our natural resources that is more important than storing the flood waters of our streams for power development. It stands in the same category with the preservation and extension of our forests. It stands on even a surer basis, for Man, either wilfully or through neglect, can destroy the forests, but he can never diminish in the smallest degree the power of running water. It is a great solar engine, perennial and perpetual in its action. It requires no aid from Man in its production. All he has to do is to utilize it. Providentially, electricity has unfolded its power to transmit this energy over great distances, and has thus made practicable a development which would otherwise have been impracticable. In time water-power will replace coal and oil, and will become the one great source of power, unless discoveries are made which are not now foreseen. The writer thoroughly believes in devel-

oping this power through public agencies and preserving it from private ownership and control. His present criticism is directed not at all at the principle involved, but at the extravagant expectations now being fostered as to the possible revenue which the Government may derive from such development.

The quantity of power estimated in the publications of the Geological Survey and the Agricultural Department are based upon an assumption that most engineers will question, viz., that 90% of the fall of our rivers can be utilized in effective head upon water-wheels. This is too great a figure. The most thoroughly developed river in the United States, namely, the Merrimac, in New Hampshire and Massachusetts, develops only 70% of the total head. Taking all the streams into consideration, it seems hardly possible that more than 50% of the fall can be utilized. When the fall of a river is uniform, even if quite steep, the cost of long canals or high dams necessary to concentrate it at one point often prohibits development altogether. From altitudes of 3 000 ft., the Missouri and Yellowstone, for example, descend to the sea with a total energy of possibly 5 000 000 h.p.; yet comparatively little of this can be developed advantageously. It is only in those places where Nature has helped out by concentrating the fall at cataracts or rapids that water-power development is commercially profitable. At low dams, such as are ordinarily built at lock sites, the head is often nearly all obliterated during high water. How far storage may affect these drawbacks cannot be said, but it should, of course, help a great deal. The official estimates of flow for non-regulated streams are based on two weeks' average lowest flow. This may probably be extended materially with reservoir aid or supplementary steam power. Possibly the total estimated horse-power may ultimately be realized.*

When it comes to the royalty which the Government may receive for these water-powers, if developed by private interests, the price of $20 per horse-power, adopted by the Geological Survey and the Agricultural Department, is wholly out of the question under present conditions. Possibly the writer does not understand what the figure is intended to embrace. From Mr. Leighton's articles, the inference has been drawn that wherever the work of the Government renders power

*There has recently been invented a device called a fall increaser, an adaptation of the Venturi meter, by Clemens Herschel, M. Am. Soc. C. E., which promises to utilize the extra flow of streams in time of flood water and low heads to increase and maintain the head upon the wheels. If this invention proves a success, as seems probable, it will be an immense gain to all water-powers of low head subject to large fluctuation, as would doubtless be the case in very many of those under consideration.

available which was not available before, either by building dams, as at lock sites, and thus creating a head, or by storing water which might supply powers below with more than they would have without, the value of the power thus rendered available should return to the Government $20 per horse-power per annum—an "exceedingly low price," as Mr. Leighton puts it.*

It is not understood that the Government is to build the power plants, but that this is to be done by the interests availing themselves of the privilege. Estimates of undeveloped water-powers on many streams of the Atlantic slope, by the Geological Survey, leave one to infer that these powers are considered worth at least $20 per horse-power to the Government even without dams or reservoir aid. While the statements are not clear as to what is actually meant, the various references to resources to be derived by the Government from these powers lead to the above conclusion. It would be of advantage in considering questions involving these published estimates, if the basis for this $20 price or royalty could be made more specific.

Under present conditions, or such as can be reasonably foreseen, no such royalty is possible except in extraordinarily favorable circumstances. Efforts which have been made to derive a satisfactory revenue from existing powers do not justify any such prospect. The many and various practical difficulties in exploiting these powers are rarely appreciated by those who have not encountered them in actual experience. The cost of water-power development is restricted to narrow limits, if it is to compete with coal. An engineer of high standing whose life-work has been connected with water-power development says:

"I am advised that, with good coal at $2.00 per ton in this territory, the cost of fuel per horse-power per annum (300 days of 24 hours each) is less than $8.00 for producer gas engines and for steam power about $12.50 in large size equipments. In many localities coal will cost even less than $2.00 per ton, allowing thus a still wider margin. If we now consider the usual and unavoidable handicaps and incumbrances to all water-power installations, such as floods, low water, ice-flow, back water, etc., etc., we have conditions which will make it a serious study for any power consumer to determine if the balance is not considerably against water-power in that particular territory, at this time, from a purely commercial standpoint. At any rate it must be obvious that no such rate as $20 per annum per horse-power can be paid to the

*"On the Youghiogheny alone, where it is proposed to install a slackwater system comprising three locks and dams, at an expense of $600 000, proper development of storage will insure the production of a minimum of 4 100 h. p., the value of which, reckoned on the exceedingly low price of $20 per horse-power-year, would produce a total income of $82 000."

Government by any power user for the right to draw the water only, and besides this, stand the expense of installing and operating the water plant."

Another hydraulic engineer of national reputation says:

"I think that, as a general proposition, the suggestion that all water-powers to which the Government consents should pay royalties, and especially where the parties own their riparian rights, would tend to defeat the development of most water-powers and would certainly very much curtail the number of water-power developments. I am impressed with these conclusions because of the present difficulties in financing good water-power propositions."

In *Power*, May 19th, 1908, is an article by Mr. Henry Docker Jackson, in which a critical comparison is made between steam and water-power. In this article occur the following tabulated estimates of cost of installation and of annual operation, based upon a (theoretical) installation of 1 000 h.p. The costs are averages of a number of different plants:

"PLANT COST.

Plant.	Steam.	Water.
Building and works	$10 000	$77 000
Engines, boiler, etc.	48 000	.....
Turbines and generators	15 000	17 000
Trans. lines, etc., 20 miles	.....	40 000
	$73 000	$134 000

"FIXED CHARGES.

Interest	$3 650	$6 700
Fuel, $2.50 per ton	6 160	.....
Water	600	.....
Operation	3 400	3 800
Oil, waste, etc.	770	500
Maintenance	1 500	2 680
Depreciation	3 650	3 500
Taxes	1 460	2 680
Insurance	650	.....
	$21 840	$19 860
Cost per indicated horse-power per year	$21.84	$19.86

"COST PER HORSE-POWER-YEAR.

	Steam, 88%.	Water, 95%.
100% Load factor	$24.82	$20.90
75% Load factor	39.92	32.00
50% Load factor	54.60	45.00"

From the last part of these tables, it is very evident that a royalty of $20 per horse-power would turn the scale wholly in favor of steam under all conditions of load. In fact, it is reasonably certain that $5 per horse-power per annum would be an outside figure, and even this would often be prohibitory. The situation will not necessarily be improved by the growing demand for power, but rather by the diminishing supply and increased cost of fuel. So long as coal can be had for anything like present rates, no very great charge can be realized from water-power wherever fuel is readily available. Under present conditions $120 per horse-power may be considered as an average limit for first cost of a water-power plant, if it is to compete with steam. A charge of $20 per horse-power per annum would be equivalent to doubling this first cost.*

A variable element in the cost of water-power development is the distance from plant to market, or the length of the transmission line. When this is very great, as in numerous plants in the mountain districts of the West, it makes a large addition to the cost of installation and must correspondingly reduce the royalty that could be paid for the power itself.

An interesting example of what the Forestry Service has been able to do in this line with unimproved water-powers is that of a recent permit for the development of a large power in the Cascade Mountains within the forest reserve. The beneficiary of the privilege is required to pay annually for "conservation," 10 cents per 1 000 kw-hr.—equivalent to 65 cents per horse-power per year continuous running. The right is retained by the Government to increase this charge 25% every 5 years for a period of 40 years, after which the whole arrangement may be readjusted. The maximum charge at the end of the 40 years will, therefore, not exceed $4 per horse-power.

The only way in which a rental of $20 per horse-power can be obtained with any degree of certainty, and that in only a small proportion of the localities for many years to come, is for the Government to build the plants. It is admitted that this suggestion will grate harshly on many ears because of its newness and its departure from

*Mr. Leighton cites the Falls of the Ohio as an example of an opportunity to develop 110 000 h. p. by aid of his proposed reservoir regulation. This, he states, at $20 per horse-power is 3% interest on $73 000 000. To any one familiar with the physical conditions involved in the development of this power, it will appear extremely doubtful if any company could guarantee to deliver continuously this amount of power, even with the full aid of reservoir regulation, and pay any royalty whatever.

the established ideas. But a little consideration will show it to be not only the best way for both private and public interests, but really the only practicable way. This may be illustrated by a concrete example:

The Government has just completed a survey and adopted a project for the construction of what is known as the Lake Washington Canal in the City of Seattle. It is a canal to connect Lakes Union and Washington with Puget Sound. The discharge from the tributary water-shed which will flow through the canal averages about 1 500 cu. ft. per sec. The mean fall at the lock site is about 15 ft. The theoretical energy is about 2 500 h.p., but owing to the tidal fluctuation and variations of flow with the seasons (which cannot be wholly eliminated on account of the necessity of limiting the fluctuations of level in the lakes to about 3 ft.), and also to the requirements for canal power, lockage and leakage, it was thought that about only 1 000 h.p. could be depended upon with certainty for outside use. As this power is located in the heart of a great city, it seemed as if it ought to be turned to good account in helping bear the cost of maintaining the canal. Efforts to obtain tentative propositions for developing this power were, however, wholly fruitless. The plan was then considered of having the Government build the plant and lease it to consumers of power. On this basis a tentative offer was obtained from a responsible consumer to take the plant, operate it, keep up all repairs, and pay the Government $18 per horse-power-year. Probably by the time the canal is completed, a figure of $25 can be obtained, and as more than 1 000 h.p. will probably be developed, it is likely that the Government will receive upward of $30 000 per year for this power—enough to pay the entire cost of operating the canal. The extra cost to the project of adopting the power-plant feature is $220 000, so that the revenue will be nearly 14% upon the expenditure.

In recommending this plan to the Department, it was pointed out that the true advantage of the Government, even apart from the revenue expected, favored its adoption. It simplified the whole relation between the Government and the consumer. If private interests were to build the plant, they would acquire vested rights which would always stand in the way of future control, and lead to complications if it should become necessary to terminate the arrangement. With the plant in the possession of the Government, and the

users standing simply in the relation of lessees for a limited period, without great initial expense on their part, and with freedom on the part of the Government to control the arrangement without the complication of private ownership, the whole plan would stand on a simple, practical, business basis. This view prevailed with the Department and is now before Congress for adoption, being possibly a departure in this line.

The principle involved in this case should be given general application. In addition to avoiding complications with private ownership, there are other important considerations. When a power is developed or a reservoir built, it should be so planned from the start as to bring out its full possibilities. A private company can rarely do this. Generally its scheme does not require it, nor its resources permit; but a site once occupied by an inferior work may be perpetually barred from complete development. Moreover, in any such work, the Government can derive a greater benefit than any private individual or association. A private company must build for the immediate future; it cannot wait long for dividends, and it can generally realize only on such application of the power as is possible in the immediate vicinity. The Government, on the other hand, derives all the benefits which come from the stored water anywhere on its course from the reservoir to the sea. These benefits arise from all the powers through which the water flows; from the improvement of navigation and the prevention of floods, and from every other use to which the water can be put. Furthermore, the Government is building for all time, while the individual builds only for the present and near future. The case is similar to that of landlord and tenant. A tenant cannot afford to make improvements on the farm because it is not his and he may remain on it only a short time. The most he can do is to get out of the farm what he can in its actual condition. The owner, on the other hand, can put in improvements which yield him no immediate return, because he holds the property long enough to realize upon them. So it is with the Government; it can wait for realization upon its improvements much longer than a private company. In forestry, for example, no individual can afford to wait from three to ten generations for a crop. Only the Government or a great railroad corporation can do this. Likewise, in building great reservoirs, no private company can build for the distant future. It

is only the landlord who can make such far-reaching improvements upon his estate.

Wherever, therefore, there arises any real demand for power development at the site of any Government work, as a lock and dam, the judicious course would seem to be for the Government to prepare a comprehensive plan for development capable of being carried out progressively as the market for power may justify. Let it then build the plant as fast as needed and lease it to private agencies under suitable restrictions. Likewise, when the building of a reservoir promises to be of obvious utility, and the conditions are such as to make it properly a subject of Government adoption, let the Government build it, utilizing the water in its own plants below and collecting a revenue from private plants that may use it. Whenever at the time of construction there is a direct return in sight of 2 or 3%, it should be considered justifiable from a Government point of view. The certain enhancement in the future value of such utilities and the incidental advantages in flood protection and navigation make this a conservative proposition.

That difficulties will be encountered in deriving the full return from its work to which the Government would be entitled cannot be denied. This would be the case particularly wherever it is a question of compelling existing power plants to pay for the extra water they might receive through Government storage. This question came up before the Mississippi Reservoir Board in regard to the powers at St. Anthony's Falls which derive such benefit from the reservoirs. The Board remarked as follows on the subject:

"It may be urged that if the incidental benefits of the reservoirs to the water-power interests are so great, these interests should be required to contribute something to the maintenance of the system. There would doubtless be a willingness to do this if a satisfactory method could be found. But there is no practicable method of enforcing any charge upon the use of this water. Where water is taken in a separate channel from above a dam or lock and conducted to a mill, it is a simple thing to measure it and to cut it off if it is not paid for. But when it must be let into a natural stream, where it mingles with the run-off from below, it is impossible to determine what proportion of stored water the mill may be using, or to enforce its non-use if not paid for. But, if such an arrangement is not practicable, that fact does not constitute an argument against the reservoir system. So long as the reservoirs are performing the service for which they were

created, every additional benefit derived from them is only an additional argument in their favor."

These disadvantages will adjust themselves in time.

Such, in the opinion of the writer, must be the basis of any great reservoir system in our country—industrial use. Even in the uniquely favorable conditions at the head-waters of the Mississippi, no one can doubt that the real purpose being served is that of mill power, whatever the theory upon which the reservoirs were built. The great system of the Far West is being built for irrigation, power and domestic supply. So on the Ohio and other eastern streams, the system must rest upon an industrial basis and expand only as industrial demands justify. The innovation involved in building reservoirs with public funds for these uses is admitted; but it is no greater than it was ten years ago to build them for irrigation. When the writer was investigating that subject in 1896-97, he found a widespread opposition throughout the arid regions against Government control of irrigation works in any way, and in his report he went no further than to advise the building of reservoirs for giving the people more water, leaving its distribution exactly as it was before. Yet in the short space of ten years public sentiment has completely changed and, to-day, no one questions the wisdom of the broader plan upon which these works are being carried out. So it will surely be in regard to reservoirs in all other parts of the country. The principle is the same. It may be accepted that only the General Government can do this work in the comprehensive way in which it ought to be done, because only the Government can reap all the benefits; only the Government can wait the long periods necessary for full returns, and only the Government has the necessary resources to make expenditures on the required scale. These points will not be enlarged upon, and the many and cogent reasons why this is so will not be given. The trend of public thought is all in that direction. The old idea that the Government cannot execute great works or small as cheaply, efficiently and expeditiously as private agencies is fast being dispelled, and the vast benefits which the people derive from public control of important enterprises are coming into fuller recognition all the time.

The foregoing remarks should not be construed as in any way rejecting the idea of local help by states, counties, cities, or even private

agencies. It often happens that public works have a special local importance in addition to their public value. It is just and proper in such cases that local aid be given. This principle is now fully incorporated in river and harbor legislation. For example, the Lake Washington Canal, which will be of very great local importance to the City of Seattle, is a joint enterprise between the Government and the City, the latter paying fully one-third of the cost. The co-operation between the U. S. Geological Survey and the several States in preparing a contour map of the country is an example on a large scale. The principle ought to find an extensive application in the establishment of national forests throughout the country.

Conclusion.

This paper will be closed with some reference to the relation of navigation to other uses of our streams, and to certain legal obstacles that stand in the way of comprehensive measures. That the improvement of our inland waterways should be organized upon a more rational system than it has ever been, that the reciprocal relation between navigation, water-power, etc., should be given practical recognition, above all, that the prosecution of these works should be placed upon the same sure basis as is the construction of the Panama Canal, with positive assurance that, when once commenced, funds will be forthcoming for their prompt completion, would seem to admit of no doubt. How far navigation should be correlated, in improvement work, with other uses of the streams, is an open question. Water-power and navigation are in many cases so closely related that they will have to be considered together. In regard to soil wash, no such intimate relation exists. To whatever extent soil erosion now exceeds that of former times, it relates almost exclusively to cultivation and has no appreciable influence upon the channels. Its control is of far greater importance to agriculture than it is to navigation. This is also true of irrigation, which, so far as it affects navigation at all, affects it injuriously. If the development of irrigation is ever carried to the length that we hope it may be, it will cause a heavy drain upon the low-water flow of the Missouri, Sacramento, San Joaquin and the Columbia Rivers (not important as to this stream), the only navigable waterways of consequence that are affected by it. Except for this fact of drawing water from the streams, irrigation has no relation to navigation.

Forestry, irrigation and prevention of soil wash are all related to the conservation of the vegetable resources of the country. They are kindred purposes and should naturally fall under the same administrative control. Navigation is a function of transportation, which is a very different subject. Water-power is becoming more and more closely related to it, and these two subjects naturally go together. It must not be expected that the character of works for river regulation can be materially changed by means of reservoirs, forests or soil-wash prevention. Levees and bank protection, locks and dams, dikes and dredging will continue to be standard methods of river improvement in the future as in the past. The accumulated experience of centuries in all civilized countries cannot be set aside in a moment. In particular, flood protection is not likely ever to find any complete substitute for levees. They have been used extensively the world over throughout recorded history. People who think only of the Mississippi and the Po, when levees are mentioned, little understand to what an extent "diking" is resorted to wherever rich bottom lands have to be guarded against floods or tides. Some of the finest agricultural lands in the world are behind levees where almost perfect security is felt. No class of river control is in more extensive use, none is better understood, and from none has the world, throughout its history, derived greater security and benefit.

Municipalities, like Pittsburg, Cincinnati, and Kansas City, must look in the main to their own efforts for protection against floods. In particular, they must reject absolutely the delusive promises of forestry. These cities are trespassers upon grounds dedicated by Nature to a condition of overflow. They have occupied these grounds and placed themselves in the way of the floods deliberately and with their eyes open. They have gone farther than this, and in many instances have encroached upon the channels, and have thus made the floods worse than they used to be. It is not for them now to look for outside deliverance, but they themselves should grapple courageously with the problem. In most cases these problems admit, if not of complete solution, at least of a very large measure of relief. The maxim that Providence helps them who help themselves may also apply to the Government. Co-operation in connection with its regular work, either in channel improvement or in the building of reservoirs, would doubtless be given. The disposition which must be met and

overcome is to let things go as they are, trusting blindly to chance to deal more kindly in the future. This supineness of spirit and the enervating reliance upon indefinite future relief through the agency of the Government must be replaced by self-reliance, and these great industrial centers must rise in their own might and free themselves from their bondage to these ever-recurring catastrophes. In Boston, Chicago, Galveston, San Francisco, and even that lusty young giant of the Northwest, Seattle, are examples enough of what an aroused civic spirit can do in the direction of self-aid.*

The part that reservoirs will play in the larger problems of channel improvement and flood control on the great rivers will be in the nature of an insurance. Every cubic foot of water taken from the crest of a flood and released when the rivers are lowest is *pro tanto* a benefit. If the great floods of the Mississippi can be cut down by so much as a foot through reservoir storage, it will be an immense gain; and the same will be true if the low-water stages can be increased by 2 or 3 ft. Whether the much greater results expected by Mr. Leighton can ever be realized is a question which the future alone can determine.

A word, finally, concerning the legal obstacles in the way of a broad Government policy looking to the development of National forests and the storage of water on an extensive scale. The expansion of Government work into fields of obvious utility is often blocked by the structure of our Government through the bar of constitutional prohibition or at least lack of power. It is said that the purchase of lands for the rearing of forests for timber alone is unconstitutional, and that the same is true of the storage of water for any other purpose than navigation; and yet, forests for timber and reservoirs for power must always remain the real justification for public expenditure along these lines. To the average understanding the distinction between things constitutional and things unconstitutional is often hard

*The writer is not closely familiar with the situation at Pittsburg and Cincinnati, but he is familiar with that at the two Kansas Cities where, in 1903, the greatest loss occurred that any American city ever sustained at the hands of a river flood. He speaks from the results of careful study on the ground when he states with the utmost positiveness that, for approximately $10 000 000, with such aid as might reasonably be expected from the Government on the Missouri River front, the flood problem of the Kaw and Missouri in that hive of industrial enterprise known as the West Bottoms can be solved absolutely; the too small area of these bottoms can be increased by upward of 200 acres; two-thirds of the bridges in the same area can be eliminated: that prodigious barrier to free movement—the Kaw River—can be practically removed or placed where it will not be in the way, and the general situation can be so improved that the resulting benefits, wholly apart from that of flood protection, would be well worth the cost.

to discern. The Government is now expending millions in storing water and conducting it upon land whereby the products of the soil may be obtained. It is applying this water to both public and private land, or to lands that were in private ownership when the projects began. Is there any real difference between providing the power to raise sugar beets, for instance, and that for manufacturing them into form for human consumption and transporting them to the consumer? Are not the last-mentioned purposes quite as necessary as the first?* And again, is there any distinction in principle between improving a river so that boats can navigate it and improving it so that it may provide power that will transport produce by land as well as by water?

Again, the Government has accepted gifts of land like the Yosemite Valley and the Muir Redwood Grove, to be given over to the enjoyment of the people and involving perpetual expenditures for maintenance in the future. It has traded lands of its own for lands with which it has parted ownership. It reserves vast areas to-day which might be private lands to-morrow. What is the distinction of principle between doing all these things and buying outright lands that are needed for the same or similar purposes? They are distinctions without real differences. They concern the letter and not the spirit, and they cannot stand whenever the interests of the public really demand their abrogation.

Still, it is probably a fact that Federal authority to buy lands for forest culture alone and to create reservoirs for industrial use exclusively, would be considered by the Courts as transcending the power of Congress under the Constitution, and it is this fact that forces those who believe in having the Government do these things to strain the truth by attempting to prove that they are necessary for navigation and for the prevention of floods. It enforces a policy of indirection instead of permitting these things to be done squarely for their real purpose and as a matter of right. In his address before the Judiciary Committee, in its hearing on the Appalachian Bill, Mr. Pinchot stated that that proposition must stand or fall upon the theory that the forests regulate stream flow, and are therefore useful to navigation. Did he not refer to the particular point here under

*It has even been hinted by high judicial authority that the Reclamation Act itself would not stand the test of constitutionality, if brought into Court.

consideration—that on any other theory the measure would be unconstitutional? Surely he did not mean that the cause of forestry itself must stand or fall upon any such issue.

Does not this situation suggest the necessity for an important initial step which shall sweep away these artificial barriers and let these great questions stand or fall on their intrinsic merit? If the upbuilding of new forests, if the storing of our flood waters, are necessary measures for the welfare of the Nation, the way should be cleared for their accomplishment. There may be differences of opinion about amending the Constitution in the interest of uniform divorce laws, popular election of Senators and the like, but, if we may judge from the universal agreement upon the particular subjects here considered, every State in the Union would ratify an amendment giving to Congress the power to legislate for the conservation and development of the natural resources of the country.

The writer should possibly state, in justice to the official body of engineers to which he belongs, that the arguments presented in the foregoing paper are his individual opinions only. He is not acquainted with the views of any other officer upon the subjects treated, except as he has seen them expressed in official reports or in the public press.

DISCUSSION

F. COLLINGWOOD, M. AM. SOC. C. E. (by letter).—In these days of unrest, it would seem that no conclusions in any realm of thought or observation are so firmly established but that some acute thinker will bring forth arguments to prove their unsoundness. Mr. Collingwood.

This is the case in this interesting paper, but, while acknowledging the force of the arguments advanced, the writer is unable to accept the author's deductions as a whole.

Four propositions are given, as covering the ordinarily received opinion as to the effect of forests on stream flow.

The first of these relates to the effect of the humus acting as a sponge which absorbs the rain and melting snow and pays out the water in a more equable flow. The word, "humus," does not fully cover the point involved, as consideration must be taken also of the sponge of dead leaves, and, in many cases, the great depth of moss growing upon the surface. Then, as helping in a marked degree to resist soil erosion, the matted roots of a forest must not be overlooked. These are particularly important in the case of a thin soil cover resting on sloping rock. Observation would seem to show that the young growth does not fully take the place of large trees, particularly in such locations.

It must be admitted that in time of extensive and heavy downpours of rain, when the ground is practically saturated with moisture, the effect of forests as regulators of stream flow is at a minimum; but it is not believed that it is ever entirely without effect. A rivulet which can run straight to its destination is one thing; but a rivulet which is constantly twisting and turning about obstacles of all sorts can never attain the eroding effect of the first.

The author grants that, in periods of drought, springs and streams dry up more completely when a country is deforested, which is another way of saying that forests do, in a measure, regulate the run-off. As bearing upon this point, it was the writer's good fortune, about fifty years ago, to listen to a series of lectures by the noted geologist, Professor James Hall. He stated that, in his memory, the removal of the forests from large sections of the State of New York had resulted in drying up a large portion of the springs formerly so abundant. This was especially noticeable in the removal of the watering troughs which had been so numerous along the public roads. This coincides with the writer's memory as to Chemung County, in that State.

The next point controverted by the author is that forests regulate the flow by retaining snow, which slowly melts at a later period, and thus replenishes the streams. In reply to this: the writer well remembers that, in the woods on the hills near Elmira, N. Y., the drifts

Mr. Collingwood.

remained unmelted long after every bit of snow had disappeared from the cultivated portions of the valley. It was a common remark that there was enough left to add perceptibly to the flood usually expected in June. Exposure and the kind of forest may have had something to do with this, but the fact remains.

Passing to the third proposition—that forests increase the precipitation of moisture—it is not believed that this idea is now held to any extent by meteorologists. While admitting this, it does not follow that they have no effect upon storms. Probably no person would question the statement that a chain of mountains causes most of the moisture in the clouds to be deposited on their windward side, so that the rainfall is always greater there, and less on the opposite or leeward side. If this be true, are we not forced to believe that a belt of forest must have a similar effect, but in less degree?

When there is nothing to deflect them, the several moisture-laden currents of air tend to travel parallel to each other. Let them meet a forest, and the lower current is deflected upward, and, by mingling with the upper, causes the formation of clouds and rain.

The contention, then, is that forests tend to cause a more uniform distribution of the rainfall, lessening the mighty downpour and giving more frequent gentle showers; with this would follow fewer severe winds and an amelioration of the climate. It is probable, also, that forests act electrically to induce precipitation, by restoring equilibrium between earth and clouds.

The author's fifth conclusion in summing up is that "Soil erosion does not result from forest cutting in itself," and that "The natural growth which always follows the destruction of a forest is fully as effective in preventing erosion."

The writer's contention is: That forest destruction is always followed by a more rapid flood discharge, a consecutive increase in the flood volume, a diminution in the low-water volume, and a greatly increased erosion of the banks and damage of the flood plane in the lower reaches of every stream. His opinion is based largely on his life-long knowledge of a single river, he having been born in 1839 at Elmira, N. Y., on the banks of the Chemung. The conditions in his boyhood days were these: The stream had a fairly uniform width; the banks were largely grassed; the channel was comparatively uniform; there were very few bars, and all through the summer there was a good flow of water.*

On May 31st, 1889, and the following day, there was a freshet, exceeding in height any previously known, this being the result of a very heavy and extensive rain. The writer was employed to make an

* This whole region, including the head-waters of the streams forming the Chemung, had been heavily wooded, and the cutting and rafting of pine lumber, for a market on the Lower Susquehanna, formed one of the chief industries for many years. Rafting ceased somewhere in the early Fifties, but lumbering and the cutting of hardwood for ties, fuel, etc., have continued the forest destruction.

examination and report upon the best method of protecting the City of Elmira against such floods. Mr. Collingwood.

A careful survey was made of about three miles of the river, with cross-sections every 100 ft., these being carried entirely across the flooded portion of the valley.

Having lived elsewhere for about 20 years previous to this, the writer was amazed at the extent of the changes in the stream. At one point it had widened from about 600 to about 1 300 ft. All through this portion there were bars covered with black alder, and on the south bank there was a matted mass of alders, in some places 100 ft. wide. In early days there were no alders, and the land that had been cut away was rich and arable.

At other points, over considerable areas, every particle of mould had been washed away, down to the hard clay, and the whole region was covered with coarse weeds.

In a previous survey of another portion of the river, in a dry time, the stream practically disappeared in its gravelly bed. A gentleman living on the Susquehanna, at Wyalusing, told the writer that his lands along the river, which he used to consider the best parts of his farm, were now so cut and gashed by the freshets that they had largely lost their value. Any person riding along one of the railroad lines through the valley can see the damage done by the river, often at points considerably distant from its main channel. These devastations seem to be increasing, and records of the flood heights, kept for many years at Elmira, indicate a tendency of the floods to be higher as the years roll on.

To the writer's mind, the cause is very plain. One of the streams heading into the Chemung is very steep, and, when the heavy woods were cut from its bank, the flood-waters were more rapidly concentrated, and poured into the main stream, so that the time required for the flood from a heavy rain to reach Elmira was very much shortened. The writer's recollection is that this time was reduced to one-half. The other two streams did their quota of damage, but not to the same extent. If this be true, the conclusion is irresistible: that the forests do act as powerful conservators and regulators of stream flow.

The conclusions seem sound, from another point of view: Here is a stream flowing for centuries, having a uniform regimen, with fairly uniform section and smooth banks up to, say, 50 years ago, showing, up to that time, but few signs of destruction from floods. Within 20 years there is a complete change, and a beautiful stream is transformed into an irregular, wilful, destructive thing.

If the cutting of the timber did not do it, what was it?

THOMAS P. ROBERTS, ESQ.* (by letter).—This paper covers the subject in a very broad and comprehensive manner. Mr. Roberts.

* Civil Engineer U. S. Engineer's Office Pittsburg, Pa.

Mr. Roberts. It is a curious thing that, in relation to forests and stream flow, the river engineers seem to be arrayed as a small but compact body against "popular opinion." It must be remembered, however, that the engineers concern themselves only with large areas and navigable rivers, while the views of their opponents, in the great majority of cases, are based upon observations of restricted areas and small streams. It might be contended that a collation of the reports from a multitude of such local observers should be the most trustworthy basis for national legislation bearing upon the improvement of rivers, yet it may be questioned whether this conception is not an erroneous one.

In 1885 the writer was invited to address the American Forestry Congress at its Boston meeting upon a text similar to that adopted by the author. He was warned by the Secretary of the Congress that he was in a woful minority; in fact, almost a lone man, but nevertheless the Congress would be pleased to be entertained with his theories. His paper enunciated no theories, but simply presented certain records of navigable rivers, American and European, which appeared to show nothing in support of the idea that floods were increasing in height and frequency, or that the low stages had less discharge and were more protracted, on account of any works of man. The Congress was informed that perhaps the common belief that the whole was equal to the sum of all its parts was a proposition after all not without exception, as, for instance—to refer to extreme cases—the discharges of the Colorado and Rio Grande Rivers at times make up but fractions of the united volumes of their respective upper tributaries.

At a recent meeting, a speaker, after referring to the destruction of timber by the girdling process, leaving the trunks to decay uselessly then, rose to the climax of his argument, and said:

"Again, every man knows how in the late spring the roads in the open country may be firm and dry, but upon entering the forest one is sure to find pools of water and deep mud holes. This, gentlemen, illustrates the utility of forests, and it is the whole story in a nutshell: the open country dried up and the forests abounding with countless 'miniature reservoirs.'"

It was not the whole story, however, for, later in the season, in the same region, pedestrians might have been seen hastening toward the adjoining forests to escape drenching from the summer rain squalls. Still later, during the recent drought in Western Pennsylvania, beneath the shade of trees might have been seen corn actually dead for lack of moisture, while the corn 50 ft. distant, in the same rows in the open field, while somewhat wilted, still lived and filled its ears with a medium crop. There might also have been seen in the forests saplings here and there beneath larger trees with their leaves dried up and falling off. So great, apparently, was the draft of the tap roots of the big trees for water that no moisture whatever was left for a depth

of several feet; otherwise the saplings would not have withered as they did. Mr. Roberts.

It might be asked, is the forest, in its usual late winter and spring condition, with its "miniature reservoirs" full to overflowing, capable of holding back more water from later rains than the dry open country, as described by the speaker referred to? Or, when it comes to protracted droughts, are the forest areas contributing more water to the streams than equal areas of deforested country under similar conditions of soil composition, depth, and slopes? Writing in 1838, in his first report to the Monongahela Navigation Company, the late W. Milnor Roberts, Past-President, Am. Soc. C. E., the company's engineer, states, in reference to the drought of that season, that all the tributaries of the river between Brownsville and the mouth of the Youghiogheny River, a distance of about 42 miles, were dry at their mouths, and again the same thing occurred in 1895 and is practically true at this writing.*

It appears that Colonel Chittenden must be correct in his assumption that, for the extremes of high floods and low water, as observed in our navigable rivers, forests exert no appreciable control. For the intermediate, or what might be termed summer, freshets, there is apparently some reason to think that forests have a measurable influence in reducing their height and prolonging their discharge, and this statement may hold, notwithstanding that less rainfall reaches the earth in forests than in open country. The fact is perhaps indicated for the Ohio in Table 2—for freshets not exceeding 10 ft.—and in Table 3—for the months of June and July—when the mean of freshets was 2 ft. higher in the second than in the first period. For the coal-boat stage—10 ft. or more—during the first period, the annual duration was 57.8 days; for the second period, it was 58.9 days. Doubtless the excessive rains in recent years will account for the difference in the higher stages. Speculations, however, regarding the Pittsburg river records in connection with forests, must be received with caution, in view of the fact that in eight of the counties on the Allegheny River water-shed, during the decade 1890-1900, there was a decline of more than 20 000 in the rural population, that is, exclusive of boroughs and villages, many one-time mountain farms being now covered with young trees or brush.

Table 5 shows the number of rises in the Ohio at Pittsburg, by months, reaching to or exceeding 15 and 20-ft. depths, from 1855 to 1907, inclusive. The table shows that the winter storms of January, February, and March were much more frequent in the second than in the first half period. No forest influence appears to be indicated for the leafy months, a fact contrary to the common impression.

*While it is true that the Upper Ohio, about October 1st, 1908, was lower than officially known since 1838, it is reported from East Liverpool, Ohio, that the "Indian picture writing" on a rock ledge at that place was not yet completely bared.

Mr. Roberts.

TABLE 2.—YEARLY MEAN NUMBER OF DAYS THE OHIO RIVER AT PITTSBURG REACHED THE INDICATED STAGES IN THE PERIOD SHOWN.

Years.	At or below 1 ft. stage.	Bet. 1 ft.–2 ft. stage.	Bet. 2 ft.–3 ft. stage.	Bet. 3 ft.–4 ft. stage.	Bet. 4 ft.–5 ft. stage.	Bet. 5 ft.–6 ft. stage.	Bet. 6 ft.–7 ft. stage.	Bet. 7 ft.–8 ft. stage.	Bet. 8 ft.–9 ft. stage.	Bet. 9 ft.–10 ft. stage.	Bet. 10 ft.–12 ft. stage.	Bet. 12 ft.–15 ft. stage.	Bet. 15 ft.–20 ft. stage.	Bet. 20 ft.–25 ft. stage.	Over 25 ft.
1855-1880.....	0.4	2.9	12.1	39.9	42.9	45.1	46.8	44.0	42.0	31.4	32.9	17.1	6.8	0.7	0.3
1881-1907.....	1.4	20.0	40.4	43.4	43.6	41.2	36.0	31.6	26.1	22.7	29.5	18.9	8.2	1.5	0.8

Note for Table 2.—Some confusion in stages below 3 ft. since 1885—upon completion of the first dam in the Ohio—has resulted from attempts to conform the readings below the dam to the old Pittsburg datum; hence too much importance should not be attached to differences shown in the table for periods when the river was below 3 ft.

TABLE 3.—MEAN MONTHLY HIGHEST STAGES, IN FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1855-1880.....	14.71	13.99	16.02	15.85	12.00	8.65	7.26	7.13	7.44	6.91	10.85	14.97
1881-1907.....	17.07	16.76	18.26	15.45	11.44	10.52	9.18	7.80	5.71	6.75	10.34	13.66

Note for Table 3.—But for a remarkable flood, reaching 31 ft. in September, 1861, the means of the two periods for that month would have been much the same.

TABLE 4.—MEAN MONTHLY LOWEST STAGES, IN FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1855-1880.....	3.52	3.72	5.14	5.08	3.75	2.52	2.03	1.74	1.20	1.47	2.69	3.62
1881-1907.....	4.42	5.06	5.93	5.64	4.31	3.50	2.61	2.04	1.75	2.08	3.07	4.15

TABLE 5.

Period.	JAN.		FEB.		MAR.		APR.		NOV.		DEC.		MAY.		JUN.		JULY.		AUG.		SEPT.		OCT.	
	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.
First (1855-1881).	18	4	15	4	22	5	21	3	5	1	18	5	6	3	6	1	0	0	1	1	4	2	1	0
Second (1882-1907).	29	11	27	15	30	12	17	6	2	1	11	2	7	1	2	1	4	1	2	1	1	0	2	0

SUMMARY. Mr. Roberts.

Period.	WINTER MONTHS.		LEAFY MONTHS.	
	15 ft.	20 ft.	15 ft.	20 ft.
First (1855-1881).	99	22	18	7
Second (1882-1907).	116	47	18	4

Since 1875 there has been no marked change in forest or brush-covered areas about the heads of the Ohio; while, during the winter and early spring months, covered in the second period, storms from the Gulf of Mexico, traversing the well-worn storm trail *via* Vicksburg, Chattanooga, and Charleston, W. Va., have, for some occult reason, reached Pittsburg with unprecedented frequency.

In the case of "cloudbursts," or storms of the tornado type, which, as a rule, traverse very narrow paths, few will dispute that a dense forest, by prolonging the discharge, even for brief periods, of the small streams they cross or follow, may reduce their flood heights. It is, however, from such limited areas, apt to be struck by violent storms once in from 3 to 5 years only, that reports come that are made the basis of arguments applicable to large rivers. The worst known storm of this nature, which deluged some of the suburbs of Pittsburg in 1874, raising two small runs to 15 or 20 ft. depth and destroying more than 200 human lives, affected the depth of the Ohio only about 5 ft. Hence it becomes important to differentiate the storms producing floods on small streams and on navigable rivers, as Colonel Chittenden intimates is so necessary for a complete elucidation of the subject.

In his treatment of co-ordinate topics, such as effects of forests on rainfall, dew, evaporation, erosion of slopes, silting up of rivers, and soil wash, Colonel Chittenden may be assailed by some who will differ with him in opinion. It is a mistake, however, to assume that those who endorse the author's views are antagonizing forest culture. No abler exposition, perhaps, of the importance and value of the forests has been presented than can be found in his résumé. He asks, however, that the new forests be planted convenient to the markets near the homes of the people. It is not wanton destruction on the part of the mountaineer to girdle the trees to make room for his corn and buckwheat crops, for gladly would he part with the biggest of the tree trunks for a pittance, but no offers are made him because the cost of transportation stands in the way.

So, while all of us have the same love for the trees, business considerations are very rude at times with our sentiments. We may hold

Mr. Roberts.

on to all the trees, as the Indians did, without business; but, without continued business with the trees, we cannot make homes for many more modern Americans. Yet, without more of those trees to cut, what is to be done for homes in the future? The problem is indeed a vast one, well worthy the attention of the governments, National, State, and Municipal. Confronting us, however, there are other problems, not connected with the timber question, especially that of transportation on our inland waterways, but, so long as it is contended that transportation and the forest problem are in the same category, so long will the public mind be confused by conflicting statements and arguments, and so long will decisive action be delayed.

As for the silting up of our rivers, complaints regarding it do not emanate from navigators, at least on the Ohio. The writer, as a young man, lived for four years on an engineer steamer on that river in charge of the construction of dikes or wing-dams, surveys, etc., and upon inquiry has been assured that, if any changes in conditions of navigation have occurred during the past forty years, they have been for the better. A great rise from the Cumberland and Tennessee Rivers by backwater effect may cause the deposition of much silt in the main stream, noticeable at times for 200 miles or more, but eventually comes a current amply competent to restore the channel to its former condition. From end to end the great river has this reserve of energy. The theory to the effect that with afforesting of the regions about the head-waters there will result such clarification of the waters that the river will cease to be silt-bearing, receives scant courtesy from the author. One writer argues that the sand now carried in suspension, acting like sand-paper, destroys the banks by "abrasive action." We have thus, in one breath, to consider the river banks being sand-papered down and the stream itself filling up. The Ohio between Pittsburg and Cincinnati has preserved its width between banks and its volumetric capacity very much the same for many decades, while, during the same period, that capacity has doubtless been largely exceeded by the volume of silt which the river has borne along. The author, therefore, is correct in saying that walling up the river banks would have no effect in reducing the volume of silt it transports; nothing would do that possibly for the Ohio but a tarpaulin spread over the steep hillsides of West Virginia and Kentucky, whence the greater proportion of the silt comes. Tributaries from soft-rock regions in those States can be named by the writer, from personal observation, which abounded with shifting sand-bars while yet the country about them was practically an unbroken forest. Those primeval forests did not prevent the carving of the nearly horizontal strata into the deep ravines found in the States named. If, however, the carving process is proceeding faster than formerly on some of the tributaries, troubles from it have not been reported on the main streams.

Mr. Roberts.

Regarding reservoirs to restrain floods on our Western rivers, the writer's opinions may have been perverted in youth by a parent who was in open opposition to Colonel Charles Ellet, the distinguished and able advocate of reservoirs. M. O. Leighton, Assoc. M. Am. Soc. C. E., has again raised the standard, but upon more specific and detailed lines than those of his great predecessor. It is a subject which should be considered apart from forest problems. Engineers must necessarily discuss its merits by weighing the cost with the advantages to be secured. If, for instance, it can be shown that levees along the Ohio can be built protecting all the property exposed to serious flood damages for one-fifth, or even less than one-fifth, of the cost of reservoirs necessary to secure that result, the engineers will be very apt to recommend the levee method. It requires no further surveys to hold tenable opinions on the questions herein involved. The matter of power development is, of course, a part of Mr. Leighton's project which should not be overlooked. At the same time we may have to content ourselves with fewer horses in our "power stables" than he hoped to provide. As to cost of flood-storage reservoirs in the Ohio Valley, readers are referred to an article* by Major H. C. Newcomer, Corps of Engineers, U. S. Army.

If Mr. Leighton's studies for the improvement of navigation do not meet with the results he expected, he can, in any event, congratulate himself upon showing the country where some very valuable water-powers can be found. The engineers fully appreciate the value of the elaborate topographic maps of the United States Geological Survey.

Colonel Chittenden argues that the water-powers should be under the control of the authorities managing navigation interests. They are certainly related in the cases where the powers are located immediately at dams with locks, and it seems to be apparent that the shutting down or stoppage of flow in other cases, resulting in possible detriment to transportation interests, should be under the control of the navigation engineers.

The author's final argument that all the interests of forestry, power, and water transportation are within the purview or jurisdiction of the National Government will appear reasonable to most thinkers. The revenues of the individual States, and schemes of taxation, cannot well be adapted to projects of this nature, where State lines would so frequently stop an adequate exploitation. At the late Governors' Convention in Washington no strong voice was raised against this conception. What everybody wants in this country, one would think, should be constitutional, and in the few brief words of the preamble of the Federal Constitution our wise forefathers did not forget to say something about the promotion of the general welfare. Away then with the foreign criticism that our Constitution has caged a giant incapable of development in response to modern demands.

* *Engineering News*, October 8th, 1908.

Mr. Child. STEPHEN CHILD, M. AM. SOC. C. E. (by letter).—Colonel Chittenden's arguments are so evidently based on careful study and years of practical experience that they carry great weight, and certainly one who has been able to give these matters comparatively little investigation should hesitate to combat them. The writer's interest in them, however, is intense, and, if they remain uncontroverted, they will be a strong argument for politicians in Washington who are opposed to the Appalachian and White Mountain Forest Reserve bills. As a member of the Council of the American Civic Association, it was the writer's privilege, while in Washington, to use what little influence he had in the interests of these bills, the passage of which is believed to be of the utmost importance to New England and the South Atlantic States.

The author takes up the influences of forests upon stream flow, and states "the commonly accepted opinion," "that forests have a beneficial influence on stream flow." He then proceeds to controvert these opinions pretty thoroughly. Certainly his arguments are strong and most interesting, and the writer frankly admits that he is entirely unable to meet them. As stated, the above-noted opinions are very commonly accepted at the present time, and no one is more responsible for their common acceptance in the United States than Gifford Pinchot, Assoc. Am. Soc. C. E., of the Forestry Bureau, whom the author frequently quotes and whose writings and lectures upon this subject have been accepted by many, up to the present time, as the final word on this subject. The writer, therefore, is very glad to know that Mr. Pinchot is to be given an opportunity to reply.

One of the author's statements, with reference to waste in lumbering operations, certainly appears to be extravagantly put. Commenting on the improved lumbering methods of the Weyerhauser Timber Company, he says:

> "To speak of such timber as being 'lost' to the people, 'wasted,' and its acquisition as a 'looting of our heritage,' is as disingenuous as it is untrue. Will its lumber cost the consumer a cent more per thousand than if it were from a Government reserve? It is a wholly gratuitous assumption that our timber is going to be 'wasted' unless it is placed under Government control."

While the writer is in no position to controvert the statements as to the progressive methods now being used by the Weyerhauser Timber Company, he thinks he is well within the facts in stating that the improvements which this and other progressive lumbering concerns have adopted within recent years have been due largely to the campaign of education waged by Mr. Pinchot, and to the aroused public opinion which his work has brought about. It is hard to believe, as Colonel Chittenden would intimate, that there have not been in the past and are not now, in many sections of the United States, wasteful methods of lumbering; yet the statement quoted would imply

that, and also that the Forestry Bureau, by its acquisition of Government reserves and its progressive handling thereof, has done, or can do, little good. Mr. Child.

Colonel Chittenden leads up to the decision that if the people expect to have the Government purchase land for the rearing of forests for timber, or for the storage of water for any purpose other than navigation, or upon the theory that forests regulate stream flow and, therefore, are useful to navigation, the Constitution of the United States must be amended—a small matter, which he thinks can be easily accomplished in view of the widespread interest in these questions. The writer may be pardoned for disagreeing with him and for believing that, if his arguments are correct, he has furnished Speaker Cannon and the opposition to the Appalachian and White Mountain Forest Reserve bills a two-edged sword which they will not fail to use, and he speaks from the experience of personal contact with several members of the Committee on the Judiciary of the recent Congress. In the interests of these bills, therefore, and their great importance to an immense section of the country, the writer looks forward to Mr. Pinchot's reply with great pleasure.

L. J. Le Conte, M. Am. Soc. C. E. (by letter).—The writer is greatly impressed by the intrinsic value of this remarkably well written paper. The author's remarks about Sir Gustav Wex's pamphlet on the flow of the Danube are well taken. In 1879 a second treatise was issued by the same authority, accompanied by elaborate tables and maps, and cross-sections of the river—all going to show the alleged fact that there is a decrease in the flow of water in springs, creeks, and rivers contemporaneously with an increase in the height of floods in cultivated countries. After most elaborate calculations he finally concludes that the decrease in rainfall due to this cause is found to be 0.0027 in. per annum, and the accumulated losses extending over 18 years, 0.0486 in. This refinement in the measurement of rainfall is unique. It is not at all surprising, therefore, that nearly all the meteorological stations in England, France, and Denmark, with records extending back from 100 to 120 years, failed to find any changes to speak of. Mr. Le Conte.

As far as the writer's observations extend, forests do not exercise any appreciable restraining influence on great river floods. The influence of the forest bed of vegetable humus is altogether too insignificant in amount to affect the problem.

The phenomenon of dew mentioned by the author is certainly most pronounced in the open, and at certain times of the year constitutes a very material addition to the precipitation. The writer recalls a striking experience on the San Joaquin Plains, California, while running a trial line, practically east and west, through the Town of Grayson. This was in August, when the rainfall was nothing. The line

Mr. Le Conte. passed through 40 miles of continuous and unbroken wheat field. In places the wheat stood 42 in. high, was well headed, and, when harvested, frequently averaged 60 bushels to the acre. The surveying party began work early every morning without exception, and every member, the chainmen especially, was drenched with the heavy dew on the wheat, and never got dried out until noon each day. This continued for five days while passing through this mammoth wheat field. Of course, the popular phrase "dewfall" is a misnomer. The phenomenon is purely one of condensation; nevertheless, it is a very important and material element in the daily precipitation in the open, and should not be overlooked. In the forests, of course, this is *nil*.

Another most interesting feature about these plains is the effect of cultivation on the surface run-off. Experience everywhere shows that plowing the surface soil reduces the surface run-off enormously. The reason for this is easily understood when the physical facts are known. In the natural state the surface soil is generally sun-baked and hard. When the rains come, this surface crust sheds water like the roof of a house. On the contrary, when this land is plowed up into deep furrows, after the first rains have softened the ground, all the rainfall thereafter sinks in, and the run-off is practically nothing. More than that, the top soil, being broken up and porous, stops subsequent surface evaporation enormously, and holds the ground-waters for the subsequent useful purposes of agriculture.

Of course, later in the season, when very heavy and prolonged rains come, the surface wash from the plowed lands is more heavily charged with sediment than it would have been before the lands were plowed. It should be remembered, however, that this run-off lasts for a much shorter time, and, therefore, it is an open question whether, considering the entire year, cultivation materially increases the total solids transported to the streams. The effect of cultivation, therefore, is to store the rain-waters in the soil, reduce surface evaporation, and enlarge and equalize the flow of ground-waters to the streams. These functions are certainly in keeping with the requirements of conservation, and tend to increase the percentage of annual run-off to rainfall. At all events, observations on lakes and artificial reservoirs certainly fail to show any noticeable increase in silting up due to cultivation of the soil.

The author's remarks about the relative efficiency of storage reservoirs in controlling the flood-water flow of rivers are exceedingly timely and strictly to the point. If these reservoirs are to be used for power or irrigation purposes, all efforts at flood control must be abandoned. The all-powerful interests of water-power and irrigation are diametrically opposed to storage capacity for the accommodation of great storm-waters, as these generally come at the end of the wet season. These two interests can never be reconciled, but will always

be in endless conflict. In view of the large financial interests in water-power and irrigation, it is not difficult to see the final outcome of this conflict. Mr. Le Conte.

The big artificial reservoirs at the head-waters of the Mississippi are a great object lesson. They occupy ideal sites for storage reservoirs, and such sites are extremely hard to find.

The author mentions the fact that in times of heavy rainfall it sometimes happens that reservoirs will be compelled to discharge a greater quantity of water than would flow from the lakes in their natural state, that is, they would operate to increase the floods. Here again is evidence showing the conflict with power development, where the storage room is divided between several years instead of being confined to two years, as called for by the natural development. This conflict always arises, and it cannot be prevented. Necessity calls for it, and necessity knows no law.

The grand scheme of storage reservoirs proposed for the Ohio River system is altogether too Utopian, and is utterly impracticable as applied to the control of great river floods. Let water-power development and irrigation each stand on its own bottom, which both are amply able to do. The irreconcilable conflict between irrigation and low-water navigation in great rivers is rapidly approaching and will not down.

The writer's sympathies are largely on the side of irrigation, simply because the public benefits derived therefrom are so much greater than the damages sustained by a few months' interruption of low-water navigation, which, in many rivers, does not amount to very much.

In the arid regions, where irrigation is the very life-blood of the entire community, it would be equivalent to public suicide to insist upon the rights of low-water navigation; the exigencies of the case forbid it. Here, it is well to call attention to a fact, not generally known, in reference to low-water navigation on the Ganges River in India. The head-works are located at Hurdwar, where the river leaves the foot-hills. The fall of the river at this site is from 10 to 12 ft. per mile. Below the dams the river bed is dry, the entire low-water flow being taken for irrigation. Going down stream, however, the irrigation seepage waters, together with underground flowage, increase enormously, and on reaching a point 40 or 50 miles below the dam the river is as wide and deep as it was before the head-works dam at Hurdwar was built. Later, in 1878, the engineers built a regular weir dam, with locks for slack-water navigation, lower down the river at Narora—4 miles below the railroad bridge at Rajghat. This dam also takes all the low-water flow of the Ganges at this site, and necessarily leaves the river bed dry for a few miles; and then it is as wide and deep as ever. When one considers the enormous public benefits derived, viz., 1 600 000 acres irrigated on the Main Ganges Canal, and 1 900 000

Mr. Le Conte. acres on the Lower Ganges Canal, the small damage to navigation, caused by these great public works for a few months in the year only, sinks into insignificance and, in many cases, can be entirely ignored.

Mr. Maltby. F. B. MALTBY, M. AM. SOC. C. E. (by letter).—The presentation of this paper now, while the agitation and interest in the "Conservation of Natural Resources" is at its height, is particularly fortunate, and the placing on record, in an available form, of facts of observation rather than theories or popular opinions, is of the greatest value. The writer is in thorough sympathy with the movement for the preservation, and the intelligent and careful use, of forests and other resources of the United States, but agrees most emphatically with the author that the popular belief that deforestation is responsible for floods and low waters is an erroneous one.

There are ample reasons why forests should be carefully preserved and cared for and reforestation encouraged for the sake of future timber supply, without the necessity of charging to the destruction of the forests all the ills due to flood conditions on the one hand or the deficiency of water for industrial or domestic supplies and low stages for navigation during dry seasons on the other.

The author has shown in detail the fallacy of such beliefs, and these details show the painstaking care and thought that has been given to the preparation of the paper. The writer, unfortunately, has no other facts of observation to present as an addition to the discussion, and only wishes to approve most heartily the conclusions concerning the relations between run-off and deforestation.

During the Eighties or early Nineties, in the first days of extensive improvement work on the Mississippi by the General Government, it was impossible to secure appropriations for the construction of levees, except where built as an aid to the improvement of navigation, and one or more appropriation bills expressly prohibited such expenditures except as stated. There doubtless were engineers and others who honestly believed that the construction of levees did tend to improve conditions for navigation, and there is no desire to open up a discussion on this subject at present. Any one knowing the conditions and the vast benefits which have followed the construction of levees in the Mississippi Valley, however, will agree that there was ample and sufficient reason for their construction without any reference to navigation.

It is also true that the conservation of forests, the protection against flood conditions, or the improvement of low-water navigation are each of National importance; each can stand alone on its own merits, though it is undoubtedly true that all should be carefully considered by a commission charged with a careful study, in a broad way, of the whole subject.

Mr. Maltby.

The data presented by the author, as to the relation of stream flow and reservoir effect, are also particularly valuable in refuting some of the extravagant statements made by reservoir enthusiasts. It is to be regretted that the presentation of facts, with the calm arguments and conclusions based on them, cannot be given the same publicity as some of the wild assertions and schemes of the magazine writers. This cannot be expected, as there is nothing sensational in a consideration of the facts and conditions.

That much, very much, can and should be done in the direction of forestation, water supply for power purposes and navigation, and the control of floods, is undoubtedly true; and the engineering profession is to be congratulated on having the underlying facts concerning the relations between the various subjects so clearly brought before it.

Mr. Le Baron.

J. FRANCIS LE BARON, M. AM. SOC. C. E. (by letter).—This paper is very timely, and the author has handled the subject in a very thorough manner. His observations in regard to snow run-off from forest and open areas, are borne out by the writer's experience. In his early days, while running railroad lines in New England, in the early spring, he was often surprised to find the woods nearly devoid of snow, while deep drifts still remained under the road fences and stone walls, and in deep road cuts.

The writer, however, must take exception to what he considers too sweeping a generalization of the statement that "there is really very little, theoretically, to support the claim that forests insure precipitation." It is undoubtedly true that when warm, moisture-laden air strikes a cold air current, the moisture will be precipitated in the form of rain. Forests are sometimes warm and sometimes cold. In northern latitudes forests are warm in winter and cool in summer; in the tropics, they are always cooler than the open, where the sun's rays are unimpeded. Take, for instance, the thick forests that clothe the eastern slopes of Nicaragua. For many months in the year, the warm trade-winds that have passed over the Caribbean Sea blow day after day from the coast over these forests, and the precipitation is phenomenal. It is common, when traveling on the larger rivers, to see spiral columns of vapor resembling the smoke of camp fires arising from the low hillsides when this warm wind from the sea is blowing over them. So perfect is the resemblance that at first the writer unhesitatingly supposed the vapor columns to be the smoke from the fire of some lonely hunter or settler.

There may be, as the author says, "very little to support the claim, theoretically"; but, practically, it is abundantly proven throughout the whole of that relatively narrow isthmus known as Central America, from Guatemala to Panama, as the writer has frequently observed. This phenomenon is particularly noticeable in Nicaragua, and the in-

Mr. Le Baron. fluence of the forest is there particularly observable, because that country is, in general, low, so that the excessive rainfall on the eastern side, amounting to 365 in. per year at Greytown, cannot be attributed to mountains. On the western side of that Republic, the precipitation is only about 45 in., and the forests are very different, being more open, and there are many large areas of cultivated lands and unwooded plains. All the moisture held by the eastern trade-winds is dropped when they pass over the dense and cool forest jungles that cover the entire eastern water-shed.

The author falls into another error of generalization, due, probably, to the fact that his observations have been confined to the limited area of the central and western United States. He states that "precipitation is nearly always greater upon the hills than upon the neighboring lowlands." This statement is quite true in British Columbia, where the observed rainfall in the Fraser River Valley is about 60 in., while less than 10 miles away, at Lake Coquitlam, among the mountains, but in the same water-shed, the precipitation is 130 in. On the Central American Isthmus, however, the reverse is true. While the precipitation at Greytown is 365 in., and at Bluefields, about 290 in., at Tegucigalpa, Honduras, at an elevation of 3 000 ft. above the sea, it is about 90 in., and at Suina, Nicaragua, about 260 miles from the sea, it is about 100 in. Observations were taken for two years under the writer's immediate supervision, at Greytown and vicinity and near Suina, when he was in charge of the work of the Nicaragua Canal and other and later enterprises in that country.

Touching the fourth subdivision of this paper, the author says that "the increased erosion of the soil * * * does not result from forest cutting, but from cultivation." Cultivation, however, is a concomitant of deforestation; not the intensive cultivation of the market gardener on the outskirts of a great city, but the rough cultivation of the first settler. In the broad sense of the word, deforestation is not the cutting down of the trees alone, for, as the author remarks, the stumps and roots remain and a new growth succeeds, perhaps closer and more impermeable to water erosion than before. In the sense in which we speak of the deforestation of the United States, there is meant the complete eradication of the forest, not the cutting down of the timber alone, and this includes clearing and grubbing to eradicate the trees, root and branch. That is what has actually been done in the United States and in any country that is deforested. When this is done, the soil is broken and its subsequent cultivation is of secondary importance. The trees are gone, the roots and many of the stumps are removed, the soil has been broken, and, although the land may lie fallow and be uncultivated for several years, it is exposed to the wash of the rain. The effect of this wash is very noticeable on the hill slopes in Tennessee and Georgia, and even in New England, Ohio, and on all denuded hill slopes known to the writer.

Mr. Le Baron.

In these localities the small brooks are filled with muddy water during every sharp rain. This was not so before the land was cleared, and is not so now in the adjoining woodlands.

The author states that "no possible development of forestry can increase the present percentage of forest-covered areas." This appears to be a very sweeping and unconsidered statement. To any one who has ridden over the vast prairies of the West, it is quite conceivable that Man, by irrigation or, in many places, solely by care and perseverance in judicious selection in tree planting, can and undoubtedly will in the next hundred years increase immensely the percentage of woodland, and there will still remain abundant open land for cultivation. At the same time, as the author states, many abandoned farms in the East will be grown up in wood. The writer knows of many such places in New England, and there are also many in Florida, and other Southern States, where large plantations have grown up in native forest trees since the Civil War, owing to inability to cultivate them profitably without slave labor.

The author states that the action of the forest to moderate the run-off and mitigate the severity of freshets fails entirely in heavy and long precipitation. He admits that the humus and débris in forests retain precipitation and act as a reservoir for a time, but eventually may become saturated and thenceforth will be of no value for that purpose. In an extensive forest this impounding capacity is very great, and by just so much it reduces the peak of the run-off or at least the first part of the ascending curve, and there is no proof that, by the time the forest reservoir is full, the peak of the flood may not be past.

In his third proposition, the author says that "while small springs and rivulets may dry up more than formerly, this is not true of the larger rivers." If there were no springs, rivulets, or brooks, there would be no rivers, and, if these all run dry, the large streams must run dry also.

The sixth proposition, that climate has not been appreciably modified by land clearing, may be true for large areas, in a general sense, but it has been modified, in small areas, in northern latitudes, by the added exposure to wind, so that the cold and inclemency are more pernicious for the farmer and stock grower.

In the author's discussion of the cost of hydro-electric power, using the storage reservoirs built by the Government for water conservation, he quotes an article by Mr. Henry D. Jackson, giving costs based upon averages of a number of different plants, compared with steam power. Mr. Jackson's estimate includes the cost of the dam, "Building and works, steam, $10 000, water $77 000." The author does not take into account the cost of the dam and spillway, which are supposed to be already built by the Government for another purpose, so that this estimate, as it stands, is not applicable, but should be reduced by $67 000, or

Mr. Le Baron. the cost of the dam, in favor of the hydro-electric plant. This makes a difference of 50% in first cost and the same in interest charge, and throws the balance in favor of the water-power. Therefore, his subsequent deductions are valueless.

The writer quite agrees with the author in his remarks about diking for flood protection, and about transportation by river or rail. This question of the propriety of Congress aiding navigation, and having no authority, under the Constitution, to build power works to aid transportation by rail, only exemplifies the fact that the world is growing so fast that a Constitution, which was a perfect instrument in its day, can be outgrown by the totally changed conditions of the present time.

Mr. North. EDWARD P. NORTH, M. AM. SOC. C. E.—This very able paper brings up a collateral and important question: Even if they accomplish all that is claimed for them, will National forests be a National beneficence?

The general and patent objections to the proposal now before the public are: The general installation of National forests would necessitate a still larger body of Government employees, and either tend to the perpetuation of a hierarchy, or to more or less violent changes of governmental policy.

Their control by the Central Government would impair our habits of individual initiative and also those of free association for production. These two habits, possibly more than any others, have been the governing factors in the progress of English-speaking peoples.

Their proposed locations, remote from centers of consumption for their products, by entailing the maximum cost for transportation, would diminish the resources of both producers and consumers. The fact that the General Government is a party does not obviate the necessity of making all expenditures return either insurance or profit.

As an alternative to the dedication of large areas to National forests under the control of the Central Government, and as free from the objections above recited, the following plan* seems preferable, namely, that lands covered by specified stands of trees should be free from taxation while the timber is growing and ripening. The numerous small groves which would be developed by the adoption of this measure would not be subject to the widespread destruction by fires invited by large forests, and, in addition to such modification of climate and run-off as may be due to timbered areas, would, by furnishing breeding places for insect- and vermin-eating birds, hinder, if not arrest, their extinction, besides adding to the beauty of the country; both additions not without pecuniary value. There should also be a provision of like kind for trees grown by the roadside. A prejudice against roadside trees, due to the combined effect of the trees and fences in forming

*Proposed in *The Engineering Record*, June 13th, 1908.

drifts and keeping the roadbed wet, dominates the public mind long after the watering-cart has proved inadequate to keep down the dust or prevent the raveling of the roadbed. Mr. North.

Thinking that the illustration cited (with blotting paper) would have been more valuable if the paper had been surcharged—*e. g.*, with shavings—it is not contended that erosive and disastrous floods have not originated on uncleared areas, and they are likely to recur notwithstanding any development of forest culture. Reservoirs, if of sufficient capacity, seem to be valuable adjuncts, at least, to forests, in reducing the damage from all but exceptional floods. They would also be of great importance to more valuable National interests than either the growth of timber or the prevention of soil denudation. The most important of these interests is cheap transportation, with the production it develops. Following transportation closely, and governed by it, is manufacturing.

About forty years ago our Lake commerce was limited to vessels of 7- or 8-ft. draft. Excepting for a short time in the late Seventies, Lake channels have been persistently deepened and improved, so that the tonnage of vessels has increased faster than that of freight trains on our railroads. In 1856, the year after the canal at the "Soo" was opened, the tonnage through it was 101 458. In 1907, 58 217 214 tons of freight passed through it.

Comparing the ton-mileage of our railroads with that through the "Soo," neglecting, of course, the through and local traffic not passing the locks, we have:

Ton-Mileage, etc., Reported for 1907.

Railroads as per "Poor."	233 137 507 807	0.782 cent.	$1 812 115 341
"Soo," as per "U. S. Statistical Abstract.".	48 221 465 547	0.080 cent.	38 457 345
	281 358 973 354		$1 850 572 686

The saving on this 17.1% of the total ton-mileage reported, compared with a like service by rail carriage, was more than $336 000 000. The total appropriations by the General Government for river and harbor improvements, with surveys, etc., pertaining thereto, were, up to March 2d, 1907, $552 943 025. If the ton-mileage of the Lakes not passing through the "Soo" was equal to two-thirds of that above recorded, the saving to the country by the low Lake freights was greater in 1907 than the total sums appropriated. Some will immediately object to this comparison: that the freight carried on the Lakes is of a lower classification than the average carried by railroads; but the lowering of freight rates during the season of Lake navigation has been recognized and fully understood for about thirty years, as also the increase in the high-class traffic on railroads.

Mr. North. In 1887, the first year of the admirable records kept by the U. S. Engineers at the "Soo," the ton-mileage through those locks was 4 458 544 804, which was carried at 0.230 cent, and the average railroad rate was 1.034 cents. The saving for that year was $36 026 200. If we average the 21 years we will have a rough aggregate of more than $4 000 000 000.

It would seem that a competent improvement of either the Lakes-to-Gulf waterway or of the proposed coastwise canal would result in a like increase of tonnage and an equal saving in the cost of transportation, for both routes are now offering much more traffic than was in sight or believed possible when the canal at the "Soo" was either projected or completed.

For nearly 20 years attention has been directed to the difference in growth of cities on the Lakes and in the valley of the Mississippi, where but immaterial improvements in depths have been made. And note is also taken that the progress of our centers of gravity of manufacturing values is following our centers of population, but about midway between the centers of population and the Lake front; which shows, without doubt, that the cost of transportation is a very important factor in the location of manufacturing plants.

This influence is shown in particular by the nearly total withdrawal of heavy manufacturing from the New England States, where, from 1880 to the present, the freight rates have been about 50% higher than the average rate for the whole country. It is also shown by the ruin of the iron industries of Troy and Albany, with the depopulation of the counties about the head of navigation of the Hudson, consequent on the successful effort of the Chamber of Commerce of New York City to prevent the deepening of the river channel above Coxsackie.

The foregoing considerations have led to a growing insistence in the Mississippi Valley that the wealth of that section should be augmented by increasing the navigable depth of the river. The demand was growing too strong to be ignored when it was determined to combine any plan for improved navigation with one for "the conservation of our natural resources." This is of loss and damage to the prosperity of the country through the delay necessary for the consideration of so large and complicated a project. This delay will be prolonged by the selection of our most able opponent of internal improvements as Chairman of the Inland Waterways Commission, who, after the endorsement of this extended plan at Washington in May, 1908, is understood to have announced that there would be neither Congressional consideration of the Atlantic coastwise route nor appropriations for surveys in the Mississippi Valley. At the same time, the declaration for improvements of watercourses to a "standard depth" forecasts an intention, on the part of the protagonists of this movement for con-

servation, that the issue of their labors should be a standardization of what ought to be main arteries for the exchange of products to the economic depths of the smaller subsidiary streams. So that there will be no substantial reduction in the average of our total freight rates: that production may not be encouraged and the wealth of our lower Atlantic Coast and of the Mississippi Valley may not be unduly increased as the wealth along the Great Lakes has been. Mr. North.

The extension of our manufacturing interests, which in 1905 paid out in salaries and wages $3 186 310 754 and produced values of $14 802 147 087, as well as the enlargement of the area of cheap freightage, is threatened by this conservation plan. It is understood that the Central Government proposes to seize all sources of water-power and put them under bureaucratic control. This control may be relied upon to hold the value of these natural resources so near a prohibitive price and to hamper their use by vexatious restrictions in such a way as to retard unnaturally their development. All the employees of this branch also are likely to be auxiliary to Government by executive decree.

The development of water-powers, and particularly of our timber supply, without control by the Central Government, would free the country from the danger to be apprehended, under our elective system, of large bodies of Government employees who could be made to act with nearly as much unanimity as a regiment of soldiers. The individual growers of timber, with their employees, could not be induced to act together. The lands selected would be chosen on economic grounds, without taint of political corruption or even political influence. They would be widely disseminated, mostly on the broken ground heading all our streams that do not originate in swamps, and the undisputed cooling effect of groves would break up the ascending currents from highly heated areas which dissipate possible rain clouds. The lumber they furnish would be in proximity to the demand, while the waste products of scattered groves would have a local use and value probably more than offsetting the economies of manufacture in large establishments. In both cases, the areas devoted to tree growing would not contribute directly to local taxation; but, in the case of woodlands cultivated by individual initiative, a careful selection would be made of the less productive and less easily tilled areas. Our proposed National forests, on the contrary, would include in their large areas all those fertile spots that support farmers, and cover the land with men increasingly trained to look to the Government for their means of support.

This entire scheme of Conservation of National Resources seems to be on a parity with the present demagogic demand that no more railroads should be built lest there should be ruinous competition, coupled with the claim that the return on the capital invested in railroads should be carefully limited through the supervision of our Central

Mr. North. Government instead of by the action of free competition. It seems to be planned that even our waterways—if improved—shall not compete freely.

Our best National resources are the production and consumption of our people. It is doubtful if our entire natural wealth would have sold for £5 000 when Elizabeth and Raleigh commenced exploiting this country. Until natural resources enter into destructive consumption, few of them have anything but a speculative value. Some of these resources are destroyed by their use. The power of falling water, though destroyed by that act, renews itself indefinitely, and any non-use of that power is an irremediable loss to the world's wealth. There is no impairment of value to any watercourse by its use, and, when there is money enough available for its improvement, neglect of its possible aid to production seems to be an economic crime.

Mr. Todd. A. Miller Todd, M. Am. Soc. C. E. (by letter).—The writer has read this paper with great interest. He has also read many of the treatises referred to by the author, and other literature on the subject. Having been intimately connected with the work of improvement and flood control of the Lower Mississippi River for the past fifteen years, the subject is of vital interest to him. Every suggestion as to cause and effect, as bearing particularly on great floods, has been closely studied, and also every proposed remedial measure.

Coincident with the whole country's great awakening to the value of the inland waterways, and the growing sentiment that they must be regulated and improved to the fullest extent, there has been a tendency to lay too great stress on certain conditions which are very remote from the locality in need of improvement, a change or modification of which conditions is held to be necessary in order to obtain immediate results leading to river improvement, often to the detriment of local methods and treatment sorely needed with the least possible loss of time. Particularly, there seems to be a great popular belief, even among some residents of the Lower Mississippi Valley, that deforestation is largely responsible for most of the recent great floods. Colonel Chittenden has demonstrated clearly, from indisputable data and records, that there has not been, throughout the Mississippi Valley, any perceptible increase in the number and volume of floods that could be attributable to any cause, much less to deforestation. It is true that floods produce greater disaster and suffering than in years past, but this is due solely to the fact that the population in the overflow areas has increased, and many great industrial improvements have been built up directly in the face of the fact that the ground occupied was subject to serious overflow. The writer has seen this exemplified in numerous cases, even along the Lower Mississippi. In nearly every town or city, from Cairo to New Orleans, can be found extensive and important railroad yards, depots, shops, factories, warehouses, com-

presses, dwellings, and many other improvements deliberately located and built on ground which is sure to be overflowed again; and, what is more surprising, only in a very few instances have steps been taken to protect these improvements when high water comes. Mr. Todd.

The writer does not mean to condemn reforestation as applied to forestry, having observed too many examples of wanton waste of valuable timber throughout the entire Mississippi Valley. It is doubtful if there has been anywhere a greater waste of timber than along the shores of that river. A recent magazine writer deprecates the fact that he saw "squashes and pumpkins" caving into the river with the banks and going to waste! The loss of growing crops by caving banks has been very small, compared with the great amount of merchantable timber which has been lost in the river in that way during past years; and even now there is a great annual loss. These trees, as pointed out by Colonel Chittenden, after they fall into the stream, vie with the sand-bars as to which can cause the greatest obstruction to navigation. Again, the writer has seen areas of hundreds of acres of the finest timber land cleared by deadening the trees, which are thus utterly ruined. Timber firms have acquired the timber right on lands, and have cut everything large enough to make a railroad tie with two sides flat; however, there is usually such a variety of timber growing that the land is seldom entirely cleared from this cause. Timber conservation, local or otherwise, however, would not have the slightest effect upon the regimen and flow of the lower river; and, as Colonel Chittenden well states, "no engineer could honestly advise lowering in height by a single inch the levees of the Mississippi" even if the fondest expectations of the forestry advocates could be realized.

The whole matter, of the benefit that the forestry experts expect to contribute to the ultimate improvement of navigable rivers by the application of forestry, rests on theory built up on certain rainfall data and stream gaugings collected in various sections of the country. Many of the data, though most carefully observed and compiled, are often very discrepant and misleading, owing principally to the lack of a sufficient number of gauging stations properly located and efficiently observed.

The paper by John C. Hoyt, Assoc. M. Am. Soc. C. E., on rainfall and stream flow,* and the discussions thereon bear out the foregoing statement.

It is a peculiar fact that nearly all writers and investigators of rainfall and stream flow neglect to take into consideration the influence of slope on run-off percentages. The author states:

"It is perfectly true that more rain falls on the hills than on the lowlands, that a greater percentage of rainfall runs off from steep than from flat slopes, etc."

Transactions, Am. Soc. C. E., Vol. LIX, p. 431.

Mr. Todd. In connection with a drainage project in the Mississippi Delta, in attempting to ascertain the proper percentage of run-off to rainfall, the writer was surprised to discover, from a very carefully compiled table of run-off compared with rainfall, covering the entire Mississippi Valley, that seemingly the flatter the slope the greater the percentage of run-off. The table referred to is contained in a publication by the Weather Bureau,* from which the following extract is taken:

"Normal Annual Discharge from River Basins."

"Basin.	"Ratio of discharge to downfall.
"Ohio	0.300
Upper Mississippi	0.275
Missouri	0.150
Arkansas	0.156
Red	0.220
Central Valley	0.515."

Commenting on this table, in the same publication is found the following:

"The Central Valley includes about 30 000 square miles of swamp land and 39 000 square miles of upland; the ratio over the former is doubtless much greater and over the latter much less than this average."

It is a noteworthy fact that even at this date probably less than 40% of the swamp area of the Central Valley is deforested, and where the timber has been cut, vegetable growth is very rank and luxurious, and conditions would seem to be in every way ideal for the conservation of the rainfall.

In regard to the caving banks on the Lower Mississippi, Colonel Chittenden is correct in his statement: "The problem is strictly a local one, and the remedy must be a local one."

It is a fact that neither extreme high nor low waters are very greatly to be feared as causing excessive caving; in fact it has been the writer's observation, checked by actual surveys and measurements, that the greatest amount of caving is usually coincident with periods when moderately high stages occur in succession, alternating with a drop to about a three-quarter bank-full stage. Of course, no general rule can be stated as applicable to caving banks, but in the main the foregoing conditions produce acute caving in the bends, where nearly always important levee locations and valuable plantation improvements are destroyed. Hence reforestation, no matter how generally accomplished, could not hope to cure this very distressing and acute problem of river improvement. The same conclusion is equally applicable to any effect proposed reservoir systems might have on the stages of the river. As to local forests checking caving banks, it has

*"Floods of the Mississippi River," Bulletin E, 1897, p. 27.

been the experience on the Lower Mississippi, that only one species of timber will have the slightest effect. Cypress trees, where they occur in considerable numbers, and where their roots extend far below the natural surface, have been the means of checking the caving in a few localities. However, the cypress has less value as a conservator of rainfall than any other tree found in the delta. Mr. Todd.

With reference to "reservoirs and their relation to stream flow," undoubtedly, they are more intimately connected with river regulation than forestry, yet, as a means of affording material relief from floods, especially along the Lower Mississippi, the writer is forced to the conclusion that in the main their influence can be but little felt. This conclusion is reached after a very careful study of all available data, together with an intimate experience with floods, and from a careful observation of their inception and propagation through the valley. Yet the hope is held out, by some of the advocates of the reservoir system, that it will be the means of solving the flood-control problem along the lower valley. The following is quoted from a paper* by A H. Horton, Assoc. M. Am. Soc. C. E., Assistant Engineer, U. S. Geological Survey, entitled "The Effect of the Conservation of Flow in the Ohio Basin on Floods in the Lower Mississippi":

"This paper is the result of an attempt to determine from a review of actual records the contribution made by the Ohio basin to Mississippi floods, and the effect produced on the latter by flood conservation in the former. The following facts are shown:

"(1) That the Missouri basin, by reason of its great area of flat country, is slow-spilling and floods therein do not rise with rapidity sufficient to gorge the channel of the Lower Mississippi.

"(2) That the Upper Mississippi basin, although subject to more rapid fluctuations in flow than the Missouri, is very much smaller than the latter and could not originate floods of capacity sufficient to gorge the Lower Mississippi.

"(3) That the Ohio basin discharges at maximum flow 50% more water than the Missouri and Upper Mississippi combined, and as the basin is a quick spilling one, it practically alone is the cause of floods in the Lower Mississippi.

"(4) That inasmuch as it has been shown possible to reduce floods in the Ohio, the same means will also reduce to a point well within the capacity of the Lower Mississippi channel all the floods that are likely to visit that channel."

Checked by actual occurrences, only the second of Mr. Horton's statements can be accepted as a fact. There have been times when the Missouri, practically alone, has "gorged the channel of the Lower Mississippi," or, as the writer understands the above term to mean, the exceeding of the overflow stages. The second flood of 1903, cited by Colonel Chittenden, is an example: Originating almost entirely in the Missouri Basin, the flood stage was equalled or exceeded at almost every point from Cairo to New Orleans, notwithstanding the fact

*_Engineering News_, June 11th, 1908.

Mr. Todd. that the Ohio and its tributaries were comparatively low. Great damage was caused to unleveed areas on account of the lateness of the season. Numerous very disastrous floods have been caused by the streams entering from the western slopes, culminating with stages in the Ohio and tributaries well below the flood level. Table 6 shows a few floods of the above character:

TABLE 6.

Stations.	Flood stage, in feet.	Highest Gauge Readings, in Feet.				
		1888.	1892.	1903.	1904.	1908.
Cincinnati	50.	39.8	43.2	16.0	44.4	44.1
Nashville	40.	39.3	38.8	26.8	37.6	19.3
Chattanooga	33.	27.0	13.7	11.6	16.9	12.2
St. Louis	30.	25.6	35.8	38.0	25.3	24.3
Cairo	45.	45.3	48.3	43.4	49.1	45.1
Memphis	33.	34.2	34.6	33.0	39.2	35.3
Little Rock (Arkansas River)	22.	19.2	31.2	26.2	29.4	25.9
Arkansas City	42.	45.4	50.0	45.6	49.0	49.9
Vicksburg	45.	44.2	48.4	43.2	46.9	47.9

The flood of 1892 was the greatest on record along a large portion of the lower valley up to that date, the serious balance to this flood was added by heavy rains over the Arkansas and Central Valleys.

The floods from the western slopes, when unrestrained, are always the cause of greater damage than the earlier floods out of the Ohio, usually materializing during the latter part of May or June, catching the growing crops at just the time when if destroyed they cannot be started successfully again after the overflow recedes. Hence it is evident that the Ohio is not the sole cause of damaging floods in the lower valley; and, even if they are held well down to below the danger or overflow stage, disastrous overflows may still occur below Cairo.

It cannot be denied that the reservoir system as proposed by Mr. Leighton, if executed as designed, would have some effect on the flood flow for a certain combination of excessive rainfall conditions; but, unfortunately, just the combination taken into Mr. Leighton's calculations may happen only once in a decade. The advocates of the reservoir system neglect to take into account the great natural reservoir effect of the stream beds, and they overlook the fact, fully recognized by all close observers of flood phenomena, that a very general rainfall over a tributary water-shed, may not cause any higher gauge readings, at lower stations, than the same amount of rainfall occurring over only a portion of the water-shed. In the case of the general rainfall the lower streams are backed up and act as reservoirs until the upper streams run out, and thus the flood is passed often with little, if any, higher gauge readings, but of somewhat longer duration. The reservoirs could only be of service as eliminating those floods originat-

ing entirely at the stream sources; and it is well known that floods of this character, coming by themselves, are less to be dreaded on the lower river than those from any other source. In fact, there are so many combinations of flood inception and flow that it is practically useless to undertake to deduce theoretical results from data which are insufficient and likely to be in error. The result of Mr. Horton's deductions when compared with gauge heights actually reached by moderate floods, illustrates the futility of attempting to reduce discharge to gauge height and *vice versa*. His results are given in two tables: One shows the computed reduction in gauge height at Cairo for certain flood years, assuming the reservoirs operative; the other gives the computed heights for certain gauge stations below Cairo. Mr. Horton's figures are reproduced here as Tables 7 and 8, with the reductions, stated in terms of equivalent gauge heights, added. Mr. Todd.

TABLE 7.—AMOUNT THE MAXIMUM READING OF THE CAIRO GAUGE WOULD BE REDUCED BY RESERVOIRS IN THE OHIO RIVER DRAINAGE AREA.

Year.	Reduction in gauge height at Cairo, in feet.	Equivalent gauge height,* in feet.
1880	7.0	38.6
1881	5.0	41.8
1882	7.0	44.9
1883	7.5	44.7
1884	8.5	43.3
1885	7.0	33.0
1892	6.0	42.3
1893	6.0	43.3
1897	7.0	44.7

* Figures supplied by the writer.

TABLE 8.—THE AMOUNT, IN FEET, THAT THE CREST OF VARIOUS FLOODS WOULD HAVE BEEN REDUCED AT DIFFERENT SECTIONS ON THE LOWER MISSISSIPPI HAD ONE-THIRD OF THE DRAINAGE AREA OF THE OHIO RIVER BEEN CONSERVED.

Station.	1882.	1883.	1884.	1892.	1893.	1897.	
Cairo	7.0	7.5	8.5	6.0	6.0	7.0	
Memphis	7.0	7.0	8.5	5.5	5.5	7.0	
Helena	6.0	6.5	7.0	5.0	5.0	6.5	
Mouth of White River	8.0	8.0	9.5	6.0	6.0	8.0	
Lake Providence	8.0	8.0	10.0	6.0	6.0	8.5	
Vicksburg	8.0	9.0	11.0	6.5	7.0	9.0	
Reducing above to equivalent gauge height.*							Flood* stage.
Cairo	44.9	44.7	43.3	42.3	43.3	44.7	45
Memphis	28.2	27.8	25.7	29.1	29.7	30.6	33
Helena	41.2	40.4	40.0	40.7	42.9	45.3	42
Mouth of White River	39.8	40.0	38.4	43.3	43.5	44.4	42
Lake Providence	30.2	28.5	28.4	35.8	35.8	36.0	36
Vicksburg	40.8	34.8	38.0	41.9	41.3	43.3	45

*Figures supplied by the writer.

Mr. Todd. A careful examination of Tables 7 and 8, and a comparison with the actual heights from gauge to gauge during only moderate freshets about equalling the computed restrained flow at Cairo, will show that the results obtained are radically wrong; especially the figures deduced in Table 8. Mr. Horton has all the great floods, of whatsoever source, reduced to just below the flood level at Cairo. The writer is doubtful whether this condition could ever be realized. It is not his purpose to go into the correctness of this table at present; but, considering Table 8, it is evidently seriously in error. There has never been a time when the flood stage of 45 ft. at Cairo has been about equalled or exceeded, but that the flood stages at all points below have been exceeded, and especially if a flood from the Arkansas River happened to culminate with the Cairo wave.

A good example of a high water where the flood stage at Cairo was just reached is found in the record for 1908. Table 9 compares the computed heights for 1882 with the heights actually obtained during the May-June flood in 1908.

TABLE 9.

Station.	Flood stage, in feet.	Restrained flow, as estimated* for 1882, in feet.	Heights reached by May-June flood of 1908, in feet.
Cairo	45	44.9	45.1
Memphis	33	28.2	34.3
Helena	42	41.2	44.4
Mouth of White River	42	39.8	49.5
Lake Providence	36	30.2	44.2
Vicksburg	45	40.8	47.9

*By Mr. Horton.

About the same discrepancies are evident for all the years considered by Mr. Horton. Certainly, it cannot be said that the reservoirs on the Ohio could influence in any way the heights of a freshet after it had passed Cairo. Hence Mr. Horton's conclusions as to the effects of the reservoir system on high water along the Lower Mississippi cannot be accepted as even approximately correct.

The writer is of the opinion that all the investigations and discussions as to conservation, forestry, reservoirs, etc., are valuable, and the matters treated are worthy of the fullest investigation; but it is wrong to recommend great innovations, claiming great benefits to localities, if there is any possibility that further investigations may prove the proposed plans useless for the objects considered. In reference to the work of flood control and leveeing the Lower Mississippi, there are already many persons who seize the slightest pretext to condemn the levee system as wrong in principle and execution, and, indeed, many of the current writers, while passing the levees as a "necessary evil," so to speak, seem to harbor the opinion that they

are only a makeshift at best, and that they can be eliminated ultimately by some other treatment. Some very eminent civil engineers have expressed this opinion openly, and, in the minds of some laymen, it places in a bad light the engineers of the valley who are earnestly laboring, with extremely limited means, to bring the levees to a completed state. Mr. Todd.

The writer states emphatically that the levees are a complete success, and, if the caving banks can be minimized, they can be completed with a very moderate expenditure, as compared with even the smallest of the reservoir estimates.

The needs of the Lower Mississippi, to render it navigable to the very highest degree of usefulness, are well known and thoroughly demonstrated, and these consist in three steps, as follows:

1. Complete confinement by levees, making the high- and low-water channels practically coincident;

2. Revetment of all the most serious caving reaches, without which it will never be possible entirely to complete the levee system;

3. Dredging at low water, where found necessary; and it may not be necessary after the first two steps are completed and the low-water channel is thoroughly established. Contraction works may have to be resorted to in a few instances to close up chutes and secondary channels.

Forestry and reservoirs can never be of any direct benefit. Reservoirs may serve finally, if built for other purposes, to render certain conditions of maximum and minimum flow somewhat less acute, but the amount of benefit is absolutely indeterminate beforehand, and for this reason they cannot be considered seriously by engineers on river regulation and control, at least in so far as concerns the Mississippi River below Cairo.

WILLIAM W. HARTS, M. AM. SOC. C. E.* (by letter).—The adoption of extensive projects for the reforestation of our mountain regions, and for the construction of a system of impounding reservoirs, to provide for increasing the navigable capacity of our inland rivers, to prevent floods, to create water-power, and to secure many incidental advantages, has recently been proposed and is being persistently urged as an advisable governmental policy. In two bulletins of the Department of Agriculture,† some of these ideas have been publicly advocated, and in many periodicals the officials of the U. S. Forestry Bureau have heralded their hopes and plans. These theories have been elaborated in more than sanguine terms, occasionally in engineering publications, sometimes in public addresses, and often in the popular magazines. It seems well, therefore, to scrutinize the claims of these earnest advocates, and test their theories in the light of facts not pre- Mr. Harts.

*Major, Corps of Engineers, U. S. Army.

†Nos. 143 and 144.

Mr. Harts. sented heretofore and by the application of reason and common sense. Colonel Chittenden has performed a valuable service to the country at large and to the engineering profession in calling attention to the other side of these popular arguments, and has admirably expressed his well-considered doubts of the feasibility of these projects and his conviction as to their many inherent fallacies.

A careful perusal of this paper should convince even the skeptical that many of the claims of these advocates of forestry are unsound, and that this entire subject, as now being urged, should be reconsidered, so that a more rational programme may be proposed if this important matter is to receive the support of the people of the country. It has all along been suspected that much of the literature on these subjects was not well supported by facts, and now the arguments and records brought forward by the author give little comfort to those who have put such apparent faith in forestation as a panacea for so many ills.

The writer has had exceptional opportunities for observing the action of rainfall and snow on mountain sides, in several years' travel over the Sierra Mountains, in connection with the work of the California Débris Commission. In general, the worst scour from rainfall may be said to have been found in cultivated fields, where the land had been cleared and plowed. Deforestation, apparently, had not much effect on the land wash, as a second growth promptly sprang up, practically as useful for protecting the ground surface as the original forest, if not even better when its effect during the snowy seasons is considered. Even when burned over, no immediate scour of the ground occurred, to any noticeable extent, and a new growth at once appeared, which in a few years seemed to become practically as effective as the first.

In observing the action of melting snow, the effect mentioned by the author was particularly noticeable. On bare hillsides there were usually snowdrifts in gullies and valleys, where they formed excellent reservoirs for equalizing the flow. A warm rain in the spring, on the other hand, usually brought down a large part of the snow covering the ground in the forests, where the sun's rays were not allowed full effect. The most severe and destructive floods in the Columbia River are those following a warm rain in early spring, when the snow cover is melted and its volume is added to that of the rainfall.

In like manner the theory of reservoirs is also singularly defective. Its weak points are easily exposed, and its fallacies may be made plain with a little study.

As a fertile field for academic discussion, however, the doctrine of impounding the flood waters of rivers in their upper portions, to be liberated later as needed during low stages, for the conservancy of the water-power, for the benefit of navigation, and for many other pur-

poses, offers fine opportunities to the enthusiastic theorist. The average man of intelligence is accustomed at the present time to regard preventable waste as an almost criminal loss. The theory that the flood waters of our rivers, now causing so much damage, may be retained behind enormous dams for later profitable use at low stages is so plausible and attractive that it is little to be wondered at that the propaganda of this theory at present being persistently urged by its advocates should find many earnest listeners. This is especially so as only the merits of such a system are thus far being dilated upon. The public, however, is obviously entitled to the benefit of comments on the project as seen from the practical viewpoint. Mr. Harts.

There are so many glittering possibilities apparently connected with the theory, such as the diminution of floods, the development of enormous and presumably profitable water-powers, material assistance in the effort to reclaim flooded areas, and increased depths for navigable rivers (to say nothing of incidental benefits to fisheries, irrigation, forestry, and other interests), that it is not strange that these possibilities should be eagerly accepted at first glance as being easily within reach of the people. On the other hand, any attempt to analyze and view in their proper proportions the enormous difficulties that must be overcome before even moderate success in this direction can be expected, may be subjected to harsh criticism; but, obviously, the defects of the proposed system should not be concealed.

The method of conserving the flood waters of rivers by controllable reservoirs is by no means new. It was tried on the Loire, in France, about two centuries ago.* In Germany and Russia, and also in America, this method of storing the flood waters of rivers has been attempted. The results, up to the present, have been such that its extension for flood control, in most if not all of the countries in which it has been tried, has been abandoned and its application condemned by the highest exponents of engineering skill. Messrs. L. F. Vernon-Harcourt and R. Rawlinson in England, M. Malézieux in France, and Mr. W. Milnor Roberts, Colonel William E. Merrill, General H. L. Abbot, and many other distinguished engineers in America, have reported strongly against its adoption. The high reputation of these men as experienced and practical river engineers is well known.

It may be claimed by the supporters of the theory that in the few actual applications of their principles (in each of which the natural conditions were especially favorable) the system has given some satisfaction. According to reports, it has been applied on the Volga and Msta Rivers, in Russia, which are provided in their upper portions with vast natural reservoirs in the shape of inland lakes, where the plan was easy to establish, requiring but few flowage rights and in-

*"Rivers and Canals," Vernon-Harcourt, p. 221.

Mr. Harts.

expensive dams; a natural reservoir system was, in effect, already in existence.*

It is also reported that this system was tried in France early in the last century. In 1856 investigations were made with a view to determining whether it should be applied to the Seine, Loire, Rhône, and Garonne, for flood control. These resulted in the decision not to construct the reservoirs proposed for these streams, owing to the "uncertainty and doubtful efficacy of their action." In 1875 this matter was again examined in France, with a similar result; so that in 1881 we find the reservoir system for controlling floods on these streams definitely abandoned by the official engineering organization of the French Republic.†

In America the experiment has been tried on the Upper Mississippi in what are known as the Lake Winnibigoshish, Lake Pokegama, Leech Lake, and other reservoirs. These also were in a naturally favorable location, where almost all the land to be overflowed was unoccupied, practically valueless, and already largely covered by lakes. The cost of the early surveys for these reservoirs was paid by those corporations which were exploiting the water-powers near St. Anthony's Falls, as they were to be incidentally large beneficiaries under the system.‡ Much of the present-day enthusiasm for reservoirs, when traced to its logical head, would in all probability likewise be found to emanate from those who were expecting to benefit, at Government expense, out of the power feature. It seems now to be admitted by many that the Mississippi reservoir system as an accessory to the navigability of the river was originally urged by the water-power companies as a subterfuge to cover their designs of securing more power at public expense.

These Mississippi reservoirs have now been in existence many years, and notwithstanding that they are the largest in the world used for this purpose, having an actual storage of more than 93 000 000 000 cu. ft., and have developed valuable water-powers at Minneapolis and elsewhere, the effect on the navigability of the Mississippi River at St. Paul has been so slight and the difficulty of maintenance so great that the extension of the system to the St. Croix, Chippewa, and Wisconsin Rivers for the benefit of navigation has been definitely reported against by several boards of engineers constituted to examine the subject.§ The reservoir method for the improvement of navigation on the Ohio River, advocated by Charles Ellet, Jr., in 1849 and subsequently, was examined in 1873 by a board of engineers, and an unfavorable report was submitted after careful study.|| These adverse reports were not made through any lack of appreciation of the enormous benefits to be

*Annual Report, Chief of Engineers, U. S. Army, 1898, p. 2850.
†*Annales des Ponts et Chaussées*, 6th Series, Vol. II., 1881.
‡Annual Report, Chief of Engineers, 1870-71, p. 283.
§Annual Reports, Chief of Engineers, 1881, p. 2753, and 1887, p. 1692.
||Annual Report, Chief of Engineers, 1873, p. 541.

derived if the system could be successfully and practically applied, but were based on its inherent defects, which were considered so serious as entirely to overwhelm its advantages. Mr. Harts.

In their publications, the advocates of the reservoir system lay much stress on the increased depths that are practicable by releasing certain quantities of water at low river stages. No mention, however, is made of the the fact—and sight of it seems completely lost—that depths due to additional flow are invariably less the farther downstream the observations go, and that the theoretical discharge necessary for navigable depths is not the same at all points along the same stream. The Ohio and Tennessee are not canals having uniform widths, depths, and slopes.

Navigation depends, not on maximum depths, but on minimum depths; so that, when use by boats is referred to, it is of no value to say that we may have 5 ft. of water in our river, when at shoal places there may not be more than 2 or 3 ft. These minimum depths determine the limit of use to be made of the stream. Ordinarily, the depths of channels vary with natural conditions. Where rivers widen, the depths grow relatively less. To say that we may have a 5-ft. depth in the Tennessee River at Knoxville, Chattanooga, or Riverton, by no means proves that at Colbert Shoals, Muscle Shoals, and various other places, the depths would be as great. As a matter of fact, the depths on the gauges at these towns bear only a remote relationship to the navigable depths on the shoals. As the discharge of the Tennessee increases, the slope at Colbert Shoals decreases; while at the "Suck" the slope increases, owing to the gorging effect of the banks. Local conditions thus affect the flow to an important degree.

Then, too, it is believed that the reservoirs would soon fill with silt. All reservoirs must necessarily be located near the head-waters of the streams, since nowhere else will land be cheap enough or otherwise available for this purpose. In such localities the erosion in the water-shed is at a maximum, the slopes of all streams being steeper in their upper than in their lower portions. In the case of the Tennessee River it is found that the area claimed to be available for furnishing water for the reservoirs specified covers a water-shed of 19 520 sq. miles. The scour from this area is enormous, and is now carried down mainly at high water. It cannot be claimed by the most enthusiastic supporters of this theory that these reservoirs would not rapidly fill with silt due to this erosion. It is folly to claim that the hillsides draining into the reservoirs can ever be adequately protected against this scour by forests. As mentioned above, the production of silt in river valleys is due far more to the cultivation of fields and farms than to the cutting away of the large trees of the forests, as these are promptly followed by a second growth almost as useful as the first for protective purposes. The cleared farms are

Mr. Harts. usually valuable, and will be vacated in favor of forests only after a bitter struggle. Forestation is independent of the reservoir system in any event, and can protect the hillsides as well without reservoirs as with them.

Experience shows that most dams for the production of water-power are sooner or later filled with silt unless special precautions are taken to sluice out these accumulations into the rivers below, where they will inevitably form shoals and bars in the reduced currents. This sluicing is at best a precarious operation. Thus the dilemma of ruined reservoirs or injured rivers must be faced.

The dam at Austin, Tex., which failed some years ago, was found to have had its storage capacity materially diminished by a large quantity of sediment, so much so that it is admitted that in a few years it would have ceased to be an effective reservoir.* Within three years after its completion its capacity had been reduced 38%, and it was estimated by Professor T. V. Taylor that in 40 years its capacity would have been diminished 98 per cent. No methods of sluicing out this sediment are yet satisfactory, and the operation, if attempted at all, would be attended, it is generally admitted, with great danger to the structure and with much uncertainty. Do the advocates of this plan rely on sluicing into the lower rivers these deposits of silt and sediment? Unless they do, it seems certain that their reservoirs would sooner or later be ruined.

The wash in all parts of the country is not alike, and the rates of filling behind reservoir dams would vary. The scour in the arid regions of the West, as along the Colorado River, would probably far exceed the rate in the Mississippi Valley, and this would likewise far exceed that of New England. We are told by the advocates of forestry that the Mississippi River carries billions of tons of sediment annually into the Gulf, and it is undeniable that a large part of this sediment comes from the region in which it is proposed to erect dams for reservoirs.

That the power that can be generated from flowing water is often valuable in localities favorable to its consumption cannot be gainsaid; nor can it be denied that this feature is relied upon by the advocates of the reservoir theory for its main support. Wherever great reservoirs have been constructed, in the past, the primary purpose has been an industrial one, with other considerations distinctly secondary. To what extent navigation will benefit from such a secondary consideration it is not difficult to predict. As Colonel Chittenden has stated:†

"The function of reservoirs will always be primarily the promotion of industrial ends; secondarily only, a possible amelioration of flood conditions in the rivers.

*_Engineering News_, Feb. 22d, 1900.

†In the Annual Report of the Chief of Engineers for 1898, p. 2878.

"While it is perhaps physically practicable to build reservoirs of sufficient aggregate capacity on the water-shed of any stream, even so large a stream as the Mississippi, as to exercise some influence in diminishing the height of floods, the great cost of such works, as compared with the results to be expected from them, will always prohibit their construction, unless it is called for by other and more direct causes." Mr. Harts.

The effort to combine in one plan the improvement of depths in navigable rivers, the diminution of flood waves to a safe point, and the utilization of the stored water for electrical power can never be satisfactory to any single interest. To prevent floods, the reservoirs should be empty until the danger of floods is past; and, for furnishing water for navigation or power, they should be full when the dry season approaches. The difficulties attending the operation of a single reservoir to meet these divergent demands may be guessed at; but what shall be said of those involved in the combined operation of many?

Captain E. H. Schulz, Corps of Engineers, states in his report on the reservoirs of the Upper Mississippi:*

"It is endeavored to operate the reservoirs to the best advantage for the general welfare. Daily reports are received from each of them and from gauge stations along the river, and the orders to the dam tenders are changed from day to day to best meet the requirements of the situation. The reservoirs affect seven different interests which often conflict—steamboat navigation below St. Paul, steamboat navigation above St. Paul, logging, mills at Minneapolis, mills above Minneapolis, riparian owners on the river, and riparian owners on the reservoirs. It is impossible to so manage the reservoirs as to suit all concerned, because each party minimizes or ignores entirely the interests of all the others. The reservoirs are being so managed as to benefit in the course of the year, every one of the seven interests concerned except the riparian owners on the reservoirs, who have been, or are being, compensated in cash. Each of these interests is materially better off than it would be if the reservoirs did not exist, but none are entirely satisfied, and some very much dissatisfied, because each would like the reservoirs managed exclusively for its own benefit, so that it might receive, if possible, all of the great public good which the reservoir system is intended to accomplish and does accomplish."

It is well known that powerful corporations are at present eagerly securing the best water-powers available for future development, for their own benefit, on the best terms obtainable. The earliest surveys of the reservoir sites of the Upper Mississippi were undertaken at the instance of the private companies owning water-power dams at Minneapolis, and although this work was ordered by Congress and done under the direction of General G. K. Warren, the expenses of the first examination and survey were paid for by these corporations.

This project, being urged as it was from its very inception by the water-power companies at Minneapolis, has never inspired the usual

*Annual Report, Chief of Engineers, 1907, p. 1584.

Mr. Harts. hearty enthusiasm of the engineer officers in charge of the work, as seems plain in reading their many reports. Whether the interests of navigation were the predominant ones, or whether the incidental benefits were the most important, it is clear that Congress, in appropriating money for these reservoirs, intended to accept no responsibility for the expenditure of public funds in such a way as to make private benefits the main object of the appropriation. In the law of July 5th, 1884, we find the following:

"For continuing operations at the headwaters of the Mississippi River, sixty thousand dollars: *Provided,* That the money hereby appropriated shall be used solely for the improvement of the navigation of the Mississippi River and its tributaries, and no part thereof shall be expended with the view to the improvement of private property."

It would solve many questions if the United States could be involved in this question so that its right of eminent domain could be used to obtain possession of such areas as are necessary for the production of water-power for industrial purposes. There seems, however, to be no warrant in law for such a course. The following is quoted from General Mackenzie's report on the questionable legality of any such efforts:*

"Regarding the proposition to empower the Secretary of War to authorize the use and development of the water-power at localities not improved by the United States, it should be borne in mind that natural water-power—that is, power made available by the existence of natural falls and rapids in a river—is appurtenant to riparian ownership, and the right to use it is governed by State laws on the subject of private property. As above set forth, the Federal Government can regulate and control it only to such extent as may be necessary in the interest of navigation."

It may be pertinently asked whether these dams and their controlling works could be operated successfully if built. Even assuming the reservoirs in place, all legal questions of riparian and other ownership solved, the safety of the dams assured, and the system ready and waiting to spread far and wide its benefits, would there be found any one competent to regulate the flow of water through these dams, taken as a system, so that when a flood threatened the reservoirs would be empty to receive it, and when a drouth came they would be full and ready to supply water for navigation, water-power, irrigation, and other necessities? Is it within the scope of ordinary human ability to do such work without constant and vital errors, and with any degree of satisfaction to those affected? We know how difficult it is to predict, even a few hours ahead, what will happen in the way of precipitation. Does it seem reasonable to expect the regulation of the flow

*Cir. 13, Office, Chief of Engineers, 1905.

of the stored water to be any more exact or satisfactory than our weather predictions? Colonel Chittenden, in discussing the use of reservoirs for preventing floods in the Sacramento River, says:* Mr. Harts.

"It must be remembered that a fatal obstacle to the perfect handling of any system of reservoirs, from the point of view of flood protection, is that Science has as yet furnished no means of predicting climatic conditions with any degree of certainty. It can never be foretold when or in what magnitude storms will come, and, therefore, the only safe plan to follow, if reservoirs are to be kept in use for purposes of preventing floods, is always to keep them as nearly empty as possible; but this, as previously stated, is contrary to the policy required if they are to be used for industrial purposes."

The question of cost is a vital and conclusive one. In the Ohio Valley the officials of the Geological Survey have estimated the cost of the work at $125 219 000 for the entire system.† This estimate was carefully examined by Major H. C. Newcomer, Corps of Engineers,‡ who found, after a detailed reconnoissance of many dam and reservoir sites in the Upper Ohio tributaries, that this question had by no means been carefully studied. Major Newcomer found that the estimate would vastly exceed the figures given, and, according to his calculations, amounted to $72 757 731 for the Monongahela River Basin, $44 531 056 for the Allegheny River Basin, and $901 915 905 for the Ohio River Basin. In other words, the estimates of the Geological Survey seem to be much too small. It seems absurd to think that the American people will regard favorably the expenditure of any such sum in testing what is nothing more than a doubtful experiment. Whatever else may be said about this system, no one can claim that it offers a satisfactory argument in the direction of economy.

After the installation of a reservoir, the unwholesome conditions arising from decaying matter in the reservoir, exposed to the sun after the water has been drawn off, and the invasion of the riparian rights of individuals would still cause bitter litigation. The results of these actions, as to the time and money involved, could not be foreseen.

Although the reservoir system at the head-waters of the Mississippi has been in existence for more than 24 years, all claims in litigation have not yet been settled. The reservoirs in question are located as favorably for minimum land damages as any could be in this country. The land when the system was first adopted was wild, unoccupied, strewn with lakes and ponds, and almost valueless. In spite of this we find a record in the reports of operations showing that condemnation proceedings were still necessary in 1899 to extinguish claims for damages, and private injuries are still being paid for in cash.

Transactions, Am. Soc. C. E., Vol. LXI, p. 347.
†*Engineering News*, May 7th, 1908.
‡*Engineering News*, October 8th, 1908.

Mr. Harts. In general, it may be stated that the rights of riparian owners have never been definitely ascertained. "They are as ancient as the riparian settlements, and are inevitably a thorn in the impounder's side." As stated by Fanning:*

"The Courts and Legislatures of the manufacturing States have wrestled with this question, their judges have grown hoary while they pondered it, and their attorneys have prospered, and yet who shall say what riparian rights shall be, until the Court has considered all anew."

Nor must we by any chance overlook the danger of such a system. Our memories are still fresh with regard to the disastrous flood at Johnstown, caused by a breached dam on the South Fork of the Little Conemaugh River, Pa. This dam failed on May 31st, 1889, causing a loss of 2 280 lives and from $3 000 000 to $4 000 000. The Bouzey Dam, near Epinal, France, failed on April 27th, 1895, resulting in the loss of nearly 150 lives. Only a few months ago the Hauser Lake Dam, built at a cost of about $1 500 000, failed, causing the complete destruction of the Village of Craig, Mont. The dam at Austin, Tex., failed in 1900, on account of neglect to protect properly an insufficient foundation, although the cross-section was of good design.

The number of successful dams undoubtedly far exceeds the failures; but the best practice of the most skilful engineers can never remove entirely the danger of failure. The storage of enormous quantities of water far above the levels of the populous valleys would be a constant and terrible menace to all enterprises. No one can fail to realize that the destruction would be tremendous in case of failure of one of these dams, so that the values of all manufacturing, real estate, and other property in the threatened areas would be affected. For it must be remembered that these dams would necessarily be placed, in many cases, where foundations are inadequate, where rock is not readily obtainable, and where exact knowledge as to conditions of construction is not to be secured. Local conditions in the Southern Appalachians are not as favorable for reservoir construction as in the regions farther north where the rock has been bared by glacial action.

In the case of the Tennessee River Basin, we see a dam proposed for the French Broad, one of its tributaries, having a height of 200 ft., and impounding 199 600 000 000 cu. ft. of water. The height of the South Fork Dam above Johnstown, Pa., was about 70 ft., and its capacity was 466 000 000 cu. ft. The dam now proposed for the French Broad River is nearly three times as high and has a storage capacity of more than 400 times as much water. In case of failure of such a dam there would be no warning, and the effect might perhaps be measured by the Johnstown flood. Nothing could save the lower parts of Knoxville and Chattanooga from widespread ruin,

*"Treatise on Hydraulic and Water Supply Engineering," 1887, p. 85.

and all villages, bridges, canals, and other structures along the banks would be swept away in the general flood. One such disaster might easily be considered to outweigh all the benefits received or expected from the entire system. Mr. Harts.

Let us now examine into the effectiveness of the system. In addition to the statement of a board of engineers that the reservoir system on the head-waters of the Mississippi was producing benefits probably commensurate with its cost, and hence should not be abandoned,* we also have the statements of two former boards which, after mature consideration, recommended against the extension of the system to other rivers. Although the Mississippi reservoirs are the largest in the world used for such purposes, the increase in navigable depth at St. Paul, 350 miles down stream, is only a little more than 1 ft. at low water. In the Annual Report of the Chief of Engineers for 1881, p. 2753, is found the following:

"In recapitulation, the conclusions of the Commission may be stated as follows:

"First. The system of works in progress on the Mississippi River between St. Paul and the mouth of the Illinois River, with the modifications which experience will suggest, is adequate for the improvement of navigation, and should be pushed rapidly to completion.

"Second. A sufficient improvement of the river is not to be expected from the action of a system of reservoirs alone.

"Third. It is possible that on the completion of the observations now in progress, some of the proposed reservoirs which furnish water at the least cost, may be found to be economical aids to the principal system of channel contraction. But they should only be built when the works for channel contraction approved have been carried to the fullest economical development."

In the Annual Report of the Chief of Engineers for 1887, p. 1692, is found the following (referring to the Mississippi River):

"The region already occupied by reservoirs is exceptionally well suited for the system, and the dams have accomplished all that was reasonably to be expected from them. They now 'adequately improve navigation' in the sense that they render a fair return for their cost; and in the opinion of the Board they should be completed by raising the Pokegama Dam 2 feet and by building a dam in the Sandy Lake district, as recommended by Major Allen, if more elaborate surveys there confirm present indications.

"The Board does not favor the extension of the system to the St. Croix, the Chippewa, and the Wisconsin at present. It is believed that funds applied to the bed of the river in contraction works, dredging crests of troublesome bars, etc., will yield a better return. That method has proved effective so far as applied to the Upper Mississippi, and it will be soon enough to consider the advisability of reinforcing it by new reservoir systems when the necessity therefor has been demonstrated."

*Annual Report, Chief of Engineers, 1906, p. 1470

Mr. Harts. In reporting on the improvement of the Ohio, in 1873, an engineer board commented as follows:*

"The Board are decidedly of the opinion that there are but two possible ways of securing such a permanent depth of water in the Ohio River as its importance demands, the first of which is that advocated by the late Charles Ellet, a highly distinguished civil engineer, which proposed storing up the surplus water of floods in reservoirs near the head-waters of the tributary streams; and the second is the ordinary plan of slack-water, which has long been in use on the Monongahela and other rivers, and which was ably presented by Mr. W. Milnor Roberts, formerly United States civil engineer in charge of the improvement of the Ohio River.

"The first of these plans the board deem impracticable on account of the difficulty, if not impossibility, of finding locations for the necessary reservoirs, the immense cost of the system, its interference with the navigation of the tributaries on which the dams are located, its injury to agricultural, mining, and railroad interests in the valleys of these rivers, the difficulty of regulating the supply from the reservoirs, and the terrible effects that would be caused by accidents.

"Mr. Ellet proposed dams 100 feet high, ponding back twenty-five miles of water. Should one such dam burst—and several such casualties are on record—all others below it would be sure to break, and a terrific flood would sweep down the river, destroying bridges, river-craft, houses, and thousands of human lives. For these reasons, which we do not think it necessary to elaborate, the board are decidedly of the opinion that the reservoir plan should be unqualifiedly rejected and that the slack-water system alone deserves investigation."

In France, as mentioned above, this subject was examined with a view to learning whether reservoirs actually diminished to any useful degree the danger of floods. The following is an abstract† of a paper by M. Gros, published in the *Annales des Ponts et Chaussées*, on "The Insufficiency of Reservoirs for Diminishing the Danger of Floods:"

"The utility of reservoirs in diminishing damage from floods was taken into consideration, in France, after the inundations of 1856. Investigations were made in the valleys of the Seine, the Rhone, the Loire, the Garonne, and other important rivers, and resulted in the decision not to carry out the numerous reservoirs which had been proposed, owing to the uncertainty and doubtful efficacy of their action on floods.

"Similar investigations were made on these rivers after the inundations of 1875. These latter observations showed, in the case of the Garonne, that a reservoir capacity of 720 000 000 cubic yards would be required to protect Toulouse from a similar flood, and two or three times larger to protect Agen and the rest of the basin. The Saint-Ferréol reservoir, supplying the Canal du Midi, which has been cited as a specimen of the reservoirs that should be constructed, has only a capacity of under 8 000 000 cubic yards, so that a very great number

*Annual Report, Chief of Engineers, 1873, p. 541.

†*Minutes of Proceedings*, Inst. C. E., Vol. LXVI, p. 408.

of similar reservoirs would be required for protecting effectually the basin of the Garonne. The capacity, however, of the reservoirs which would be of value in reducing the height of floods, and could be constructed in the upper valley of the Garonne, would amount to only one-sixth of that required for protecting Toulouse. The investigations led to similar conclusions in the case of the lower Garonne, and of the other principal river basins of France.' Mr. Harts.

"The distribution of rain and advantages of situation would oblige the reservoirs to be placed as much as possible in the hilly portion of the basins, where, however, owing to the declivity, the reservoirs would be smaller, and would be liable to be rapidly filled up with detritus. It might also sometimes happen that a flood would be produced by a heavy rainfall in the lower part of a river valley, as was the case in the great flood of the Garonne in 1875, and then the reservoirs in the hills would be useless.

"The action, moreover, of reservoirs on the river further down, with an increasing discharge, becomes rapidly less Thus a lowering of the Rhone at Lyons of 3¼ feet, by means of reservoirs above, would amount to only 1½ foot below the confluence of the Saône, and to only 8 inches below the confluence of the Isère at Valence. In like manner a retention of 130 000 000 cubic yards on the Garonne at Toulouse would only act like a retention of 65 000 000 at the mouth of the Tarn, of only 52 000 000 at Agen, and of only 23 000 000 at Tonneins, and its effect would become insignificant at Langon. This shows how large the reservoirs in the upper valleys would have to be made to produce an adequate effect in the lower portions of the rivers. Reservoirs on tributaries, by retarding a flood, would modify the flow in the main river in a variety of ways, which could hardly be determined beforehand, and might be injurious by causing a coincidence of floods.

"Often continuous floods are produced by the coming down of several high floods at short intervals apart. Thus the inundation of the valley of the Garonne in 1856 was caused by five successive floods, keeping the river in flood for more than two months. Under such circumstances the reservoirs would be filled by the first flood, and would not be available for lowering the subsequent floods. The reservoir embankments might be endangered by the flow of water over them, and a failure of an embankment might entail more disasters than a very high flood.

"It has been proposed that flood reservoirs should be also utilized for supplying canals, for irrigation, and for water power, thus serving a double purpose. Flood reservoirs, however, to be useful against floods, must be kept empty throughout the whole season when floods may occur. Storage reservoirs have small outlets, and a flood discharge would have to flow over the embankment, or over a wide overfall weir. Such an arrangement might be adopted in a rocky valley, and where the discharge of a river is small; whilst the erection of high embankments across the lower valleys, where the discharge is large and the ground liable to be eroded by the fall of the water, would be dangerous.

"The system of reservoirs for providing against floods must accordingly be entirely abandoned, not only on account of the excessive expense and difficulty of obtaining adequate capacity, but also because a carefully designed system of reservoirs along a river valley, which

Mr. Harts. might provide against a flood occurring under definite conditions, would be totally inadequate to cope with all the various combinations of distribution of rainfall and floods of tributaries, by which floods are produced in the main river."

In a "Discussion on the Conservancy of Rivers,"* Mr. L. F Vernon-Harcourt is reported as saying that flood storage reservoirs had been proposed for torrential rivers, and might possibly be adopted with advantage where deep valleys, with narrow gorges, would admit of a large volume of water being retained by a short high dam.

"This system had, indeed, been partially adopted on the Loire; but the extension of this system on that river, and its adoption on the Yonne, had been rejected on economical grounds. The valleys of gently-flowing rivers were not suited for storage reservoirs. The lands bordering on these rivers were too valuable to be devoted to such a purpose; and the long duration of winter floods would render such reservoirs of little avail. It must suffice, in most cases, to provide against summer inundations; and high winter floods must be allowed to flow over the land, except where towns were liable to be flooded."

Further on (p. 291) Mr. R. Rawlinson remarked that rivers in a civilized country had two purposes to serve, which were in some degree antagonistic.

"Those who used them for navigation wished to put them in an effective state to accomplish that purpose; those who wished to prevent land flooding would act in a different way; they would not care much about the navigation if floods could be kept from their lands.* But there, again, the question was complicated. There were riparian owners who would be glad to have floods kept off their land if they had not much to pay for it, while others would say that if the floods were kept off their lands they would be seriously injured. The proposition had been to prevent floods by making reservoirs, and it had been stated that in some continental countries that system had been tried. He could only say that any engineer who made himself acquainted with meteorology, and with the volume of water that came down in excessive floods, would soon abandon the idea of forming impounding reservoirs to prevent flooding."

Referring to the same subject, M. de Lagréné stated (p. 309) that the authors [of the two papers under discussion] were right to reject large impounding reservoirs, as, in order to be of use, they would have to be placed low down in the valleys, where the land was generally most valuable, and their construction would be costly.

"Also, their functions would be exercised at times irregular and far apart, and they would induce serious opposition from the neighboring inhabitants.

"Longitudinal banks, notwithstanding their occasional failure, offered the best preservation against floods, but certain considerations

Minutes of Proceedings, Inst. C. E., Vol. LXVII, p. 287.

attached to their establishment. For instance, as no absolute knowledge could be obtained of the height of future floods, no ordinary embankment should be considered as offering absolute security, and the riverside owners should understand that bursting of the bank was a contingency to be allowed for, which it would be prudent to meet by some sort of accident assurance. Further, it was advisable not to make the banks unnecessarily long, because the more scope allowed to a flood the less dangerous it became, and consequently the less scour would occur in the river-bed and banks." Mr. Harts.

And M. Malézieux, in his communication on the subject (p. 312), stated that about twenty years before, much attention had been directed to this means of preventing, or at least diminishing, the effects of floods:

"Vast reservoirs were to be made, kept empty during the dry season, in which might be retained the water from heavy rainfalls, so that it might be released progressively and at preconcerted times, in such a way as to prevent the coincidence and the accumulation of the flood water from several rivers of the same basin. It had been found, however, that this plan, very simple in theory, would be difficult and uncertain in practice, and that it might under some circumstances do more harm than good. This was referred to in a paper in the 'Annales des Ponts et Chaussées,' vol. ii. of 1881, p. 6."

In spite of its theoretical advantages, we see this reservoir system condemned for practical reasons, in several countries, by distinguished engineers, after mature study. It is now resurrected and advocated in the United States, mainly by men who have had no experience in the improvement of rivers for the benefit of navigation or in the practical control of floods. They are endeavoring to establish a system theoretically designed to combine various utilities, but which, like the combination tool, "is the joy of the inventor, but the despair of the user."

It seems clear that, to justify the high cost, their main efforts will necessarily be directed toward producing profitable water-power first; then to the secondary benefits, such as the interests of forestry, attempting flood control, assisting in the reclamation of flooded areas, and perhaps finally including the improvement of navigation. That our rivers would obtain any decided benefit from such a project, or that it could be practically applied, needs a more convincing argument and more accurate and pertinent facts than any that have been thus far advanced.

Dr. George Otis Smith* (by letter).—Colonel Chittenden's paper on the relation of forests to stream flow is especially suggestive to all who have had opportunity to observe forests and streams. It is indeed a subject for practical men, and inasmuch as geology, like engineering, is a practical science, it may be appropriate for a Fellow of the Mr. Smith.

* Director, United States Geological Survey.

Mr. Smith. Geological Society of America to join the Members of the American Society of Civil Engineers in a discussion of the paper.

While the author has everywhere exhibited the engineer's desire to cover the ground thoroughly, his presentation of the subject omits any mention of important factors that lie beneath the surface, and the writer desires to call attention to certain of these well-known geologic conditions, although time has not permitted him to elucidate them with the thoroughness that characterizes the paper, and also to record a few observations made in the course of his geologic field work in the West, which apparently run counter to those cited by the author.

In the discussion of the effect of forests on rainfall, the illustration used at the very beginning of the paper impresses the geologist as defective, and does not seem to "apply perfectly" in assuming a "practically impervious" subsoil or rock floor. Every geologist who has investigated underground waters would pronounce such an assumption as quite contrary to the facts and, indeed, did the assumed conditions actually exist, large areas of the United States would be without potable water. Throughout the paper the author's failure to see any disposition for precipitation other than by immediate run-off and evaporation apparently leads him into a fundamental error that vitiates all his conclusions as to the effect of forests. In many parts of the country the underground supply—the water that saturates the soils and rocks—not only surpasses the surface flow in quality, but also exceeds it in quantity. The underground circulation of water is, therefore, not a negligible but a most important factor. This is indeed the important factor in maintaining stream flow during dry periods, and the beneficial effects that geologists generally believe forests to exert are exerted through their influence upon sub-surface storage and circulation.

In his casual mention of springs, Colonel Chittenden apparently regards these as of superficial and local origin rather than as marking the points of issue of water which may have traveled slowly for long distances and possibly at considerable depths. Again, many who have shared with the author the advantage of studying rivers at their sources will not agree with him that springs and small streams exercise but little regulative effect on large rivers. On the contrary, in the case of streams without lakes or artificial reservoirs along their courses, all the dry-season flow may be regarded as being maintained by the slow escape into the stream channels, by seepage or more definite springs, of water stored in the underground reservoirs earlier in the year, when rain was falling or snow melting.

Keeping in mind the existence of underground water, it is at least interesting to review the forest argument. The forest mulch not only acts as a temporary reservoir of limited capacity, but it contributes its

stored water downward, as well as outward, into the subjacent soil and rock as well as into the surface rivulets and streams. Similar diversion of a part of the precipitation into the ground-water supply takes place in cleared land, but not, it is believed, to the same degree, except where, under exceptional circumstances, the soil and subsoil is as open as it is under the forest mulch. The ability of the forest bed to delay run-off is admitted by Colonel Chittenden, who considers it likely to aggravate floods, in the logic of which deduction, however, the writer cannot follow him—at least this aggravation of flood conditions certainly cannot be regarded as an "unquestionable tendency of forests." Rather this retarding action of the forest mulch will tend to increase the proportion of the rainfall contributed to the underground reservoir, thus reducing the amount immediately converted into run-off. Decreasing the rate of surface flow increases the time and opportunity for absorption by the pervious soil and rock beneath the forest mulch. This absorptive action must to a large extent make complete saturation of the forest bed of rare occurrence, and the only general areas where "the percentage of retention in the forest bed is 0" would be the tree-covered swamps, swamps ordinarily indicating the area where the ground-water table reaches the surface. This increased contribution to the ground-water reservoir, from which the progress of water to its point of issue, where it joins the surface drainage, is indirect and slow, cannot fail to counteract in some degree, sometimes in a very marked degree, the fluctuations in that part of stream flow originating in direct run-off. The persistence of springs during the period of minimum run-off is a matter of common observation, and is explained by the long and tortuous character of the underground route followed by the water, as contrasted with the surface route of direct run-off. Mr. Smith.

The question may be raised whether this function of the forests in increasing the contribution to the underground flow is quantitatively important. The drying up of springs, with the extensive cutting off of the forests, is a well-known and widespread phenomenon, and one that bears directly on this point, though Colonel Chittenden doubtless places slight value on its importance. The most definite data that have come under the writer's observation, as to the rate at which pervious rock will absorb surface water, indicate that in a short distance the amount so absorbed from a small stream is sufficient to be readily detected and even measured, being several second-feet in the case under observation.* Moreover, the conditions in a stream bed are not altogether favorable for such absorption—by reason of the silting up of the pores of the rock—probably less favorable than under the forest mulch. Indeed it appears reasonable that as a general rule the

* U. S. Geological Survey, Water-Supply Paper No. 55, p. 56.

Mr. Smith. contribution through the underground circulation will continue just as long as the forest bed retains any portion of the rainfall.

The author's view, that delayed melting of snow is not beneficial, must also be challenged. While the writer too has found dry ground beneath a dwindling snow bank, on digging into the sand he has discovered the water beneath. Again, it seems probable that the bottom, as well as the top, of the snow cover is also a melting surface both in the open and in the forest. This is shown by the manner in which certain spring flowering plants penetrate the snow wherever the cover becomes thin. Thus it appears reasonable to believe that the time of snow-melting is a period of contribution to the underground flow, and the total contribution from snow is necessarily largest where conditions favor the longest period of melting.

On the subject of the influence of forests on snow-melting, observations will differ somewhat. As contrasted with Colonel Chittenden's excellent and detailed observations in the Yellowstone Park, the writer might mention the fact that even later in the same season, July 1st, 1899, on Table Mountain, in Central Washington, there was snow in the forest at an elevation of 6 000 ft., while, at the same elevation in the open, the snow had long disappeared, and the flood conditions on the Yakima River had passed. At one place in the forest on Table Mountain, the drifted snow was so deep on this date that the writer's horse was stalled and had to be dug out, so that, as in Colonel Chittenden's case, the difficulties attending travel forcibly drew attention to the depth of snow. Furthermore, the abundant springs of ice-cold water below the escarpment of Table Mountain, which persist through the summer, suggest that the snow banks in the forest above were contributing to the underground supply rather than to direct run-off.

The illustration, Fig. 1, Plate XL, is of a stream (White River, Washington), the water-shed of which is not aptly described as "the most densely wooded and perfectly protected water-shed in existence." White River is a glacial stream, as its name indicates, and has a well-deserved reputation for devastating floods. It has its principal source in the largest glacier on Mount Rainier, and, as the writer knows from observation, 23 sq. miles of the Mount Rainier portion of its water-shed are not forested, but are covered with ice and snow twelve months of the year, not to mention other snow-covered areas near the crest of the Cascades and at least 50 sq. miles of burnt and cut-over land in the lower portions of its basin. This fact explains why a warm "chinook" will cause the White to rise much more quickly than its sister stream, the Green, which, as its name suggests, has no glacial tributaries. The ranchers in the Lower White River Valley recognize the advantage of the high-water stage of the Green and Cedar Rivers reaching the valley after the maximum flow of Upper White River has passed. The Skagit

of which mention is also made by Colonel Chittenden, is another river receiving important contributions from glaciers and snow fields. Mr. Smith.

Unfortunately, the stream-gauging records of the Geological Survey do not afford data for a direct comparison of the White River with neighboring streams, the water-sheds of which are wholly forested. At the time of the 1906 flood, to which Colonel Chittenden refers, only two of the Cascade streams for which complete records are available failed to record the highest stage of water on November 15th. Of the two streams which reached their maximum flow on the day preceding, one, Johnson Creek, has an unforested drainage basin and the other, Tieton River, has its origin in glaciers on the main range, not many miles from the head-waters of White River. Were stream-gauging records available for White River, the writer is confident that they would show that this stream, like the Tieton, reached its maximum stage at least 24 hours earlier than the streams in the same general region having drainage basins altogether forested.

GEORGE F. SWAIN, M. AM. SOC. C. E. (by letter).—The Society should be grateful to Colonel Chittenden for the interesting paper which he has presented, and for the able and forceful way in which he has discussed the question of the effect of forests and reservoirs on stream flow. His remarks are so well presented that upon a first reading those who believe in forest preservation might feel that their side of the case had received a severe blow, but a careful examination discloses many apparently contradictory statements, while the argument seems quite as conjectural and the specific statements quite as much without proof as those given by the writers with whom the author disagrees. As a matter of fact, he seems to admit most of what is claimed for forests. So far as his paper may be considered a protest against extreme views, the writer agrees with him, though many of his statements are extreme in the other direction, and are certainly unsound. Mr. Swain.

It is a characteristic of humanity to go to extremes, and at the present time, apparently, some people almost believe that if the country could be reforested there would be no freshets, and that our streams would be absolutely uniform in flow. On the other hand, occasionally but rarely a writer is found who denies their beneficial effect, and now the author seems to be attempting to convince us that, not only forests, but reservoirs, increase the violence of freshets.

The author has stated very clearly the difficulties attending quantitative demonstration in regard to this matter. In fact, absolute proof is almost impossible, for the reason that the factor to be studied cannot be isolated in the way that is possible in many scientific investigations. In order to demonstrate quantitatively beyond peradventure the effect of forests, it would be necessary to have the same area under identical conditions in every respect, except that at one time it should be wooded

Mr. Swain. and at another time deforested. It must also be borne in mind that other factors in the problem are more important than the forests, for instance, the amount and, particularly, the distribution of the rainfall. When, in two successive years, with practically the same rainfall in each year, the same water-shed shows a run-off of about 12 in. in one year and about 17 in. in the next, the difficulty of the problem will be apparent.

However, means of forming reliable opinions upon the more important aspects of this matter are not wanting, although some minor points will probably long remain matters of opinion.

The author first considers the relation of forests to stream flow, and states that:

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(1) By storing the waters from rains and melting snow * * * preventing their rapid rush to the streams and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off.

"(2) By retarding the snow-melting in the spring and prolonging the run-off from that source.

"(3) By increasing the precipitation.

"(4) By preventing erosion of the soil on steep slopes and thereby protecting watercourses, canals, reservoirs and similar works from accumulations of silt."

This will probably be admitted to be a fair statement of what the believers in the benefits of forests consider to be true, except that some do not think that there is yet sufficient demonstration that they increase the rainfall, although the writer believes that they do.

With reference to the first of these points, the author states that it is "strictly true for average conditions." He says: "It is true, therefore, as popularly understood, that, in periods of ordinary rainfall, with sufficient intervals for the forest bed to dry out somewhat, forests do exert a regulative effect upon run-off. They modify freshets and torrents and prolong the run-off after storms have passed, and thus realize in greater or less perfection the commonly accepted theory." He believes, however, that this beneficial effect is not exerted under extreme conditions, *i. e.*, great floods and excessive low waters.

After the above admission, it would seem scarcely necessary to discuss this portion of the subject further, unless, as the author seems to believe, regulation under all but extreme conditions is of little benefit. Aside from the fact that it is a benefit to have the flow regulated, even to a small extent, during the greater part of the time, the writer cannot agree with the author that extreme conditions alone determine the character and cost of river control. The erosion of the land, the washing away of banks, the silting up and changing of channels, and the destruction of property, occur in the case of moderate floods as well as in the case of excessive floods; although, of

course, extreme conditions determine certain elements, such as the height of levees. A few great, but not extreme, floods may do more damage than one extreme flood, and may necessitate more expenditure for dredging and other purposes. Mr. Swain.

From every point of view—power, navigation, erosion, irrigation—it is of even more importance to diminish the frequency of great floods than the height of extreme floods which occur only at long intervals, and to keep up the usual low-water flow rather than the extreme low-water flow which seldom occurs.

If the writer fully understands the argument with reference to extreme floods, it appears to be this: Great floods are always the result of combinations from various tributaries, occurring after periods of long-continued and widespread precipitation; the forest bed becomes completely saturated, its storage capacity exhausted, and when this point is reached the water flows from the forest surface without restraint.

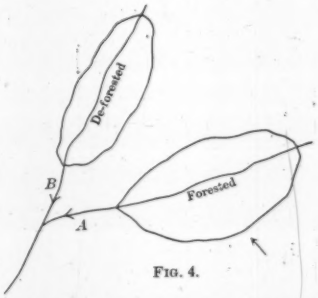


FIG. 4.

With reference to this it is, of course, evident that, when the forest bed has become fully saturated, it cannot hold any more water; but, even then, it will hinder its discharge, because the soil will not be washed away and the torrents will not flow down in gullies. In this sense the forest floor never discharges such torrents as come from unforested areas. Moreover, it is certainly a gain if forest floors can absorb even a part of the rainfall and pay it out gradually to the soil beneath, and it seems quite erroneous to urge that because their storage capacity is not unlimited it is therefore not valuable. The author states that the fact that the forest bed has retained a portion of the rainfall and will yield it up later may produce a worse condition than if the country were clear, and asserts positively, but without proof, "that the forest does promote tributary combinations there would seem to be no question, and that it may therefore aggravate flood conditions necessarily follows." Perhaps the writer does not fully understand what is intended, but he is perfectly ready to admit that a case may be imagined in which the statement of the author would be true. Suppose, for instance, a storm is moving in the direction shown by the arrow on Fig. 4. It

Mr. Swain. passes first over the forested area and later over the deforested area, both of which are about equally distant from the junction of the two streams. On account of the fact that the rainfall has been somewhat held back in the forested area, the flood coming down stream, *A*, is retarded and arrives at the junction at the same time as the flood coming down stream *B*, from the deforested area, which received the storm later, whereas, if the forest were cut down, the flood from *A* might have reached and passed the junction before the flood from *B* arrived. If this is argued as a demonstration that the cutting down of forests would benefit the streams, it is only necessary to reply that, on the contrary, it is equally an argument that the deforested area of *B* should be reforested. Besides, how would it be if the storm were moving in the other direction?

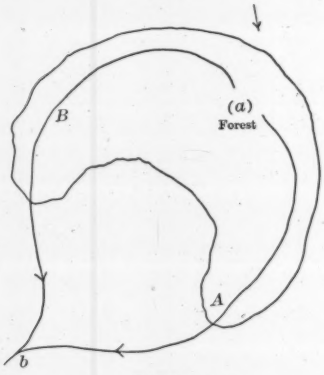


FIG. 5.

Or, to take another instance, suppose two streams have their headwaters in a region, *a*, from which the run-off reaches the junction, *b*, in about the same time from both streams, as in Fig. 5. In this case a heavy rain at the headwaters, *a*, may result in a violent combination of floods at *b*. If, however, the forests along stream *A* were cut down, the water might reach *b* *via* stream *A* before it reached it *via* stream *B*, and so the flood might be distributed at *b*. It is thus no doubt possible to conceive of cases in which the destruction of a particular forest might reduce a certain flood at a certain point, but to conclude that the resultant effect of forests is not beneficial is clearly illogical, for (in Fig. 5), the clearing of the water-shed of *A* will increase the violence of floods on that stream, while there may be little or no damage due to a heavy rise at *b* or below; and, furthermore, if the storm, instead of being stationary as just imagined, is moving, as it always is, then a movement as indicated by the arrow would have the effect that the

clearing of A would cause a combination at b which otherwise would not occur. To argue from instances like the above against the beneficial regulating influence of forests (which perhaps the author does not mean to do) would seem like arguing that because it is possible to conceive that a man's food may choke him, therefore food is not beneficial, or that the heat of the sun is not beneficial because people are sometimes sunstruck. Mr. Swain.

The author's summary of this part of the discussion is perhaps contained in the following sentences: "That the forest does promote tributary combinations, there would seem to be no question, and that it may therefore aggravate flood conditions necessarily follows. It is not contended that this increase is ever very great, but it is contended that forests never diminish great floods and that they probably do increase them somewhat."

It would seem to the writer to be nearer the truth to say that forests greatly diminish floods, although it is conceivable that some forest may slightly increase some flood at some point.

The author further states that: "The forests are virtually automatic reservoirs, not subject to intelligent control, and act just as the system of reservoirs once proposed by the French Government for the control of floods in the River Rhône would have acted, if built. These reservoirs were to have open outlets, not capable of being closed, which were intended to restrain only a portion of the flow. A careful study of their operation in certain recorded floods showed that they would actually have produced combinations more dangerous than would have occurred without them." The last sentence of this quotation is rather conjectural, and its meaning is not clear, but it will be surprising to most engineers to be told that a reservoir not subject to intelligent control does not regulate, and they will hardly accept the statement. Of course, a lake is a more efficient regulator than a forest, for reasons suggested clearly by the author.*

The general aspect of this part of the subject seems, after all, very simple. The forest floor absorbs a large amount of water, prevents it from flowing off rapidly, and pays it out gradually into the soil, through which it finds its way to springs and to the underground water. If the land were clear of vegetation, or if it were cultivated, and especially if the slopes were steep, the erosion under heavy rains would be great, and might leave no soil upon the rocks to serve as a reservoir in future storms. The author's argument, therefore, leaves unassailed the beneficial effects of forests in regulating flow; and the illustration used by Mr. Pinchot seems a reasonable example of a usual phenomenon.

The author makes a fundamental error in the very beginning of his discussion, which vitiates all his reasoning on this matter, when he illustrates the action of the forest by comparing it to the action of a

* See page 288.

Mr. Swain. layer of sand on an inclined surface practically impervious to water. The ground under the forest bed is not impervious to water, but is in fact kept by that bed in a highly absorbent condition.

The fact must be emphasized that those who believe in the beneficial effect of forests upon flow do not urge the preservation of forests on lands needed for agriculture and topographically suited for it. The beneficial effects of forests on flat lands, in modifying the violence of freshets and increasing the low-water flow, is much less clear than in the case of forests in steep mountain regions. It is the preservation of these last—forests upon steep slopes not suitable for agriculture, where the erosion on cleared land is very great—that is believed to be especially important for the streams.

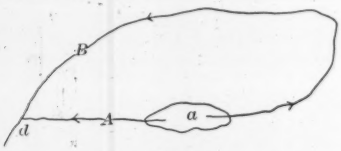


FIG. 6.

In fact, this part of the discussion seems rather academic. Probably few if any engineers will deny that lakes, even if unregulated, are or may be of great benefit in regulating the discharge of streams which flow out of them, and yet even here we may conceive of a case where the reverse would be true. Suppose, for instance, that the two streams, *A* and *B*, rise in the same mountain region, *a*, and unite at *d*, Fig. 6. If a heavy rainfall occurs at the head-waters, the part which flows *via A* will reach *d* much sooner than that which flows *via B*. Now, if a reservoir is placed on *A*, it is conceivable that it may check the flow on that stream sufficiently to make the rise of the water at *d* somewhat greater than before. But of course the flood has been reduced all the way from *a* to *d*. This simply illustrates the fact that if artificial reservoirs are to be located, their location should be carefully studied.

When it is claimed, as the writer does, that the preservation of the mountain forests will be of great benefit in regulating the flow, this does not mean that if a region is deforested the maximum flood will be greater than ever before, for the conditions are, as has been abundantly shown, extremely variable. On the Connecticut and Merrimac Rivers, for instance, the highest water ever known occurred before the present rapid cutting of timber in the upper parts of the basins. Nevertheless, it may be equally true that even those freshets would have been still worse if the forests had not been there; and it is quite certain that, if the height of extreme floods has not been increased by deforestation, the frequency and duration of great floods have. The statement* that

* See page 262.

the flood of 1908 in the Western States would have been much greater if the region had been forested is a mere statement of the author's opinion, entirely without proof, and undoubtedly incapable of a proof; and, further, if the records in Table 1 show that it is impossible to find evidence in them to support the current theory of forest influence, it may also be stated that there is nothing in them to support the author's theory. Mr. Swain.

Fortunately, however, we are not without valuable evidence in this matter, particularly in the experience in France. The work of M. Vallée, to which the author refers, was published in 1857 and was followed by two articles* by the same writer, his claim being that forests diminish rainfall and increase the violence of floods. These opinions, however, seem to have been without influence, for, in 1860, the French Government entered upon a policy of forest protection and reforestation, particularly in the mountain regions, which has been continued to the present time. To January 1st, 1900, the State had acquired, for the purpose of controlling torrents, 162 974 hectares (about 407 000 acres), and had expended upon the work of protection more than 66 million francs, with a further contemplated expenditure of more than 114 million francs, and one of the most recent writers† on the subject states: "The rôle of the forest as a regulator of the flow of streams may be considered as evident, and it is to-day universally admitted." Under the able direction of Prosper Demontzey, Chief of the Service of Reforestation in France, from 1882 until retired in 1893, and of his predecessors, much has been accomplished, and some formerly very destructive torrents have been reduced to inoffensive streams by reforestation and regulation, much more being expended for reforestation than for regulation. Perhaps it will be argued that the good results that have followed have been due entirely to regulation, and not at all to reforestation, but that is not the view of French engineers.

At first there was great opposition on the part of the inhabitants of the mountain valleys and slopes to the Government work of reforestation, and, in 1864, there were even riots in resistance, but this opposition has not only entirely ceased, but has been replaced by active cooperation. The people now frequently petition to have the Government pursue its work, and even voluntarily give up portions of their lands for the purpose, without asking any reimbursement.

With reference to extreme droughts, the author admits "that, as a general rule, springs and little streams dry up more completely than when forests covered the country," but he argues that, since each spring is small, their drying up will have little effect on the main stream, the flow of which will be kept up, if the region is deforested, by the rapid

*Annales des Ponts et Chaussées.

† G. Huffel, "Economie Forestière," 1904.

Mr. Swain. discharge of water from summer showers which will occur, first on one tributary and then on another, in such a way as to furnish to the main stream always a low-water flow greater than if the springs could all be kept up. The author objects to the illustration which Mr. Pinchot gave before the Congressional Committee, on the ground that he did not carry it far enough. If the author's argument be carried to the very common case where no rain falls upon a given drainage basin for weeks, or for a much longer time than it takes for a drop of water to flow from the most distant source to the mouth, it would seem to lead to the conclusion that there would be no flow at all in the stream. In other words, the author would have the mills at Lawrence and Lowell depend for their summer flow, not upon keeping up the "springs and little streams" so far as possible by increasing, through the effect of forests, the percolation into the ground, but would have these mills trust to luck that the summer showers would be so distributed—coming first on the Nashua River basin, then on the Contoocook River basin, the Winnipesaukee basin, etc.—that there would be a good flow at Lawrence and Lowell. This would, of course, require most intelligent planning, for it would not do to have these summer showers, which are supposed to flow rapidly from the surface, come down the different tributary basins in such a way that the water would arrive at Lawrence and Lowell at the same time. They must be accurately timed and distributed with reference to the position and size of the tributary basin.

Even a large drainage area, say 10 000 sq. miles, may well have its main stream possess a length from most distant source to mouth, measured on the stream, of considerably less than 300 miles. If the average velocity of the stream is 1 mile per hour, which is low, it would take less than two weeks for a drop of water to pass from the most distant source to the mouth. Now, even in districts which have a summer rainfall, it frequently happens that an area as large as that mentioned is without rain in any part for months at a time, under which conditions, if the writer understands the author's theory and his admission, even such a large stream would practically dry up. It would seem to be much more reasonable to depend upon some means of keeping up the springs and small streams, rather than upon the equal distribution of surface waters of summer showers from deforested areas. Of course, the larger the stream the greater the low-water flow per square mile, other things being equal, because the lowest flow from all tributaries will not arrive at a given point at the same time, partly owing, no doubt, to local rains; but it is illogical to argue from this in favor of deforestation, which admittedly reduces the lowest flow from these tributaries. The author here seems to be inconsistent. In discussing floods, he considers an extreme condition, in which the floods from various tributaries arrive simultaneously at a given point, and from this he argues generally that forests increase the violence of ex-

treme floods. In the case of extreme droughts, however, he considers the case, not where the low-water flow from various tributaries arrive simultaneously at a given point, which may equally well occur, but on the contrary where relatively high water from one arrives at the same time as low water from another. Mr. Swain.

The author, however, does not really take his own arguments seriously, for later he states: "In the records of precipitation * * * will be found a full and complete explanation of every one of the floods," and, "the true explanation is found in them and not at all in the presence or absence of forests on the water-sheds." This is quite true, except that the writer and many others believe—and the author admits—that there is abundant proof that as a rule forests reduce the violence, frequency, and duration of freshets.

The author says, "it seems certain that forests decrease somewhat the total run-off from water-sheds small or great." This would seem to depend upon the relative amount of evaporation from the forested land, and also upon whether there is an increased rainfall produced by the forests. If the rainfall is the same as without forests, while the evaporation is greater—including under the term evaporation, physical evaporation from the soil and physiological evaporation from the trees themselves—of course the total run-off will be less. Perhaps this is true. The writer does not deny that it is possible, although he has seen no proof of it to the present time; even if this is true, he believes that uniformity of flow is of much more importance than total amount of flow, even on the small tributaries which go to make a large stream. But if the forest increases the evaporation, it would seem to follow that it increases the rainfall. The rainfall is due to the condensation of the moisture in the air. This moisture comes from various sources: from the sea, from lakes and streams, or from the land. The rainfall depends upon the total amount of this moisture, independent of its source. Any cause, therefore, which increases the evaporation from a country increases the rainfall. This does not mean, of course, that if the writer increases the evaporation from his back yard, he increases the rainfall there. Large areas must be considered, and the statement is a general one. Regarding this question of rainfall, too, it must be borne in mind that the total amount of water reaching the soil is due not only to that which falls in drops from the sky, but also to that which condenses either on the ground or on the trees. The author refers to dew, which he says is not present in forests, but he does not mention the condensation upon the tree trunks and leaves, and on the ground (dew aside), which must be greater than in the open, because of the lower summer temperature not only of the air but of the trees themselves.

As to whether forests increase rainfall, the difficulties in the way of demonstration are obvious, but there is considerable proof that they do. The writer has not seen any reference to the results obtained in

Mr. Swain. Hanover, and therefore will state them. It was decided in 1887 to reforest a large area; at first from 1 000 to 1 250 acres were planted annually and, in 1891, some 18 000 acres had been reforested in pine and oak. There is a meteorological station in this region, at Lintzel. Considering a circular area of 15 000 acres with this point as its center, there were:

	Before reforestation.	After reforestation.
Cultivated ground and meadow land	12% of the area;	10% of the area.
Pasture	85% " " "	10% " " "
Forest	3% " " "	80% " " "

Rainfall observations were begun in 1882, and the results at Lintzel were compared with those at the neighboring stations of Brème and Gardelegen. The quantity of rain falling at Lintzel was as follows:

1882	64.5% of that at Brème;	96.3% of that at Gardelegen.
1883	68.7 " " " " "	101.1 " " " " "
1884	77.8 " " " " "	106.7 " " " " "
1886	83.9 " " " " "	114.2 " " " " "
1888	106.8 " " " " "	120.1 " " " " "
1890	101.6 " " " " "	120.1 " " " " "

Similar results are stated to have been obtained at Nancy, all of which are sufficient to satisfy Huffel that it rains more, other things being equal, at the center of the forest than at the edges, and more at the edges than several kilometers beyond on cultivated ground.

Whether forests decrease or increase the total run-off would seem to be still a somewhat open question. Probably it depends upon other circumstances, such as the slope of the ground, etc.

With reference to the effect of forests upon snow-melting, the author states that "it can be demonstrated that the effect of forests upon the run-off from snow is invariably to increase its intensity." It is undoubtedly true that forests reduce the formation of drifts, but the writer's observations and inquiries convince him that the snow in forests does drift to some extent, though much less than in the open, and that it lasts longer into the spring than even the drifts outside. Perhaps this is not true in the highest mountains and near the timber line, where the trees are small and the drifts very heavy, but the writer believes that it is generally true. If it is true, the author's argument on this point seems to fall. He also seems to ignore the fact that in forests the ground is warmer than it is in the open, and indeed that it frequently may not freeze at all under the snow. As the snow melts, it melts at the bottom, and the ground is more ready to absorb it than is the frozen ground in the open.

The writer has not had the opportunity to study to any extent the conditions in the Rocky Mountains, but he observes that Professor L. G. Carpenter, of the Colorado State Agricultural College—than

whom there is no more competent authority—in his paper on "Forests and Snow,"* comes to the following conclusions, among others: Mr. Swain.

(*a*). "The greater the amount of forest cover the less violent the daily fluctuation, the more uniform the flow throughout the day and throughout the season, and the later the stream maintains its flow."

(*b*). "The loss of the forest cover means more violent fluctuation during the day, greater difficulty in regulating the headgates and keeping a uniform flow in ditches, and hence an additional difficulty in the economic distribution of water. Also the water runs off sooner, hence the streams drop earlier in the summer, and on account of the lessening of the springs, the smaller is the winter flow."

(*c*). "The preservation of the forest is an absolute necessity for the interest of irrigated agriculture."

The writer is not in a position to question the statement of the author with reference to Yellowstone Park. He has observed, however, that the greater part of the Park is covered with forests. What the condition of things would be if this area were deforested can only be conjectured, and the writer would like to inquire whether Fig. 1 is simply a fictitious diagram showing the author's opinion, or whether it is based upon measurements of flow from approximately equal areas under similar conditions in every respect except that one is forested and the other not. The diagram does not coincide with the experience of the writer, which has convinced him that the snow run-off in forested areas extends later into the spring than the snow run-off on open ground.

Of course, in this, as in the other matters discussed, it is possible to conceive of circumstances under which a particular forest might increase a particular flood. If the forests retain a thick blanket of snow late into the spring, and there comes a sudden warm rain which carries away all this snow, there may result a freshet of greater violence than if the sun had previously melted the blanket of snow; but it is equally clear that if the forest had not been present, and the snow had gone off with the snow from open ground, the earlier freshets would have been increased. If a given amount of snow has got to run off into the streams, it is certainly an advantage to have the period in which it runs off lengthened.

With reference to the experience in the region of Puget Sound, the author states that the snow storms are followed by warm southerly winds and rains, which melt the snows and result in tremendous freshets and floods. A warm southerly wind and rain will easily melt 18 in. of snow even on the ground, and the author has not shown that the condition now existing would be bettered if the forests were cut down and the snowfall of 18 in. rested entirely on the ground instead of partly on the trees. His remarks on this point are an excellent illustration of illogical reasoning. He says that the great flood of 1906 "was a perfect demonstration of the vastly intensifying effect of forests

* Bulletin 55, Agricultural Experiment Station of the Agricultural College of Colorado.

Mr. Swain. upon floods due to snow melting." Would it not be more correct to say that it was simply a perfect demonstration of the fact that even in densely forested areas there may be tremendous floods?

Similarly, inconclusive, to the writer's mind, is the statement about the flood of the American River compared with Puta Creek, in California. Water-sheds differ, not only as regards forests, but in other respects. The facts stated simply seem to show that in this case the forests did not regulate the flow to an extent sufficient to counterbalance other factors. For instance, if the writer is correctly informed, the slopes of the Sierras are steeper than those of the Coast Range. Again, the shape of the drainage area is a matter of considerable importance with reference to the maximum rise of water at a given point, as has been illustrated previously in this discussion. The author, of course, may be correct in his opinions, but his statements are entirely inconclusive.

The logical position with reference to the forestry question is indeed quite similar to that of the author regarding the reservoirs on the Upper Mississippi. After showing that, as actually controlled, the flow of the river was less uniform than the natural flow (though it need not have been so), he concludes that the reservoir system "is nevertheless a very great benefit." Admitting, as the writer is ready to do, that a forest may conceivably increase the high-water stage in a given stream at a given point, it is yet safe to say that nevertheless the forests are a very great benefit as regulators of stream flow; and this conclusion is not shaken by the arguments of the author.

It must be borne in mind that of all the influences which affect the uniformity of flow of streams, but two are subject to human control, namely, forests and storage. By preserving the forests and by building storage reservoirs it is possible for Man to regulate the flow and render it comparatively uniform. The preservation of the forests is the more important of the two, and should come first, because of the erosion and consequent filling up of reservoirs which results from deforestation.

The preservation of the forests on the mountain slopes is especially important in the interests of navigation. Where they are destroyed, not only is the frequency and duration, and as a rule, the violence, of the freshets much increased, but fire often succeeds, adding to the evils by destroying the forest bed, and thus increasing the erosion. If the soil is thin, as in the White Mountains, or if it is fine and clayey, as in the Southern Appalachians, the results are almost equally bad. If, with the increasing demand for timber, these mountain slopes should be completely or largely deforested, the erosion and consequent silting up of our rivers and the impairment of navigation on account of floods and low waters, would be so great that there would be no doubt in anybody's mind of the action of the forests. But it would then be too late, and many years would be required to repair the damage, if it could be repaired at all.

Messrs. Leffingwell and Strong.

W. H. LEFFINGWELL, M. AM. SOC. C. E., and A. M. STRONG, ASSOC. M. AM. SOC. C. E. (by letter).—Colonel Chittenden's deductions in regard to the action of forests on floods are borne out very markedly in the streams of the Southern Sierras.

The control of the flood flow of these streams is of nearly as great commercial importance as that of the navigable rivers of the Middle and Eastern States. Various national, municipal, and private projects are affected by large and sudden fluctuations in the flow of the streams on which they are located. It is claimed that the floods are largely affected by the conditions of forest cover, and can be made less serious in many places by building up the forests. The Sierra Nevada Mountains, in California, upon the streams of which the State depends largely for its prosperity, have been the scene of floods which have caused great damage in recent years. This entire range has been placed in the National Forests, in order that the forest cover may be preserved and nurtured under Government control, and beneficial effects are hoped for.

Four of the principal streams in the Southern Sierras have been gauged by the Government, thus obtaining definite data on their flow. These are the Merced, Kings, and Kern Rivers on the western, and the Owens River on the eastern slope. The characteristics of their drainage areas are described as follows:*

Merced River.—Merced River drains the middle portion of the western slope of the Sierra Nevada Mountains with a drainage area of 1 090 sq. miles. The topography of the country is rough and rugged, and, in this basin, is the famous Yosemite Valley. The formation is of granite, which, on the upper reaches, rises in precipitous domes and peaks, smoothly marked by glacial action. The middle reaches of the basin are well timbered and contain the Mariposa Grove of big trees. The timber growth extends well down on the lower elevations of the foot-hills, where the covering is of brush and grass. Numerous lakes are scattered over the upper portions of the basin. The mean annual precipitation is from 25 in. in the foot-hills to 60 in. in the higher elevations, where it falls in the form of snow. The gauging station is at the lower edge of the foot-hills.

Kings River.—Kings River drains a portion of the western slope of the Sierra Nevadas, quite a little south of Merced River, and has a drainage area of 1 742 sq. miles. The crest of the Sierra Nevadas at the head of this basin reaches an elevation of more than 14 000 ft., and forms the most rugged portion of the range. A large number of small lakes on the higher elevations are fed by small streams from the perpetual snow banks and glaciers. The formation is granite, which, above an elevation of 10 000 ft., is bare. Below this elevation there is a heavy covering of timber and underbrush. Extensive groves of

* "Progress in Stream Measurements," U. S. Geological Survey.

Messrs. Leffingwell and Strong.

big trees are scattered through the basin. On the lower elevations of the foot-hills the covering is light. The gauging station is at the lower edge of the foot-hills.

Kern River.—Kern River drains 2 345 sq. miles of the western slope of the Sierra Nevadas at its extreme southern limits. It has its source in the highest elevations of the range. The topography is extremely rough and broken in the upper reaches of the basin, becoming less rugged in the middle portion, where there is quite an extensive valley. The formation is of granite, which above the 10 000-ft. contour is bare. Between 3 000 and 10 000 ft., there is a good depth of soil, with timber and brush covering; the lower reaches have a light covering of brush and grass. There are several lakes and marshes scattered through the basin, but they are less numerous than in the case of the other rivers. The precipitation is very light throughout the basin, with the possible exception of the high elevations, where the snowfall is heavy. The gauging station is at the lower edge of the foot-hills.

Owens River.—Owens River has its source in the Sierra Nevadas in Eastern California and, flowing southeast parallel with the range, finally discharges its waters into Owens Lake. This basin has a length from north to south of approximately 150 miles, with a width of from 20 to 25 miles. Practically the entire flow of this river is derived from the Sierra Nevadas, as it drains the eastern slope from opposite the head-waters of Merced River on the north to those of Kern River on the south. The gauging station is above all irrigating canals at the head of Owens River Valley and near the middle of the basin, with a drainage area of about 450 sq. miles above the station. The elevation at this point is about 5 000 ft.

The topography of the portion of the Sierra Nevadas drained by this stream is extremely rough and rugged. The formation is granite with very little soil covering, sparse timber growth, and scarcely any brush. Numerous lakes and marshes are found in the upper portions of this drainage area, above the gauging station, also a flat swampy country known as Long Valley. The precipitation is extremely light within the area of this basin, with the exception of the high elevations of the Sierra Nevadas, where there is a heavy fall of snow.

The record of the flow of these four streams is available for three years, 1904, 1905, and 1906. These include a normal season, a dry season, and a wet one, and show the flow under greatly varying seasonal rainfalls. The daily flow at the gauging station is shown in detail by the diagram, Fig. 7. It will be noted that the minimum flow of these streams is about the same, with the exception of Merced River which has much the smallest winter flow. Especial attention is called to the great fluctuations in the flow of Merced and Kings Rivers draining a timbered area; the lesser fluctuation of Kern River drain-

Messrs. Leffingwell and Strong.

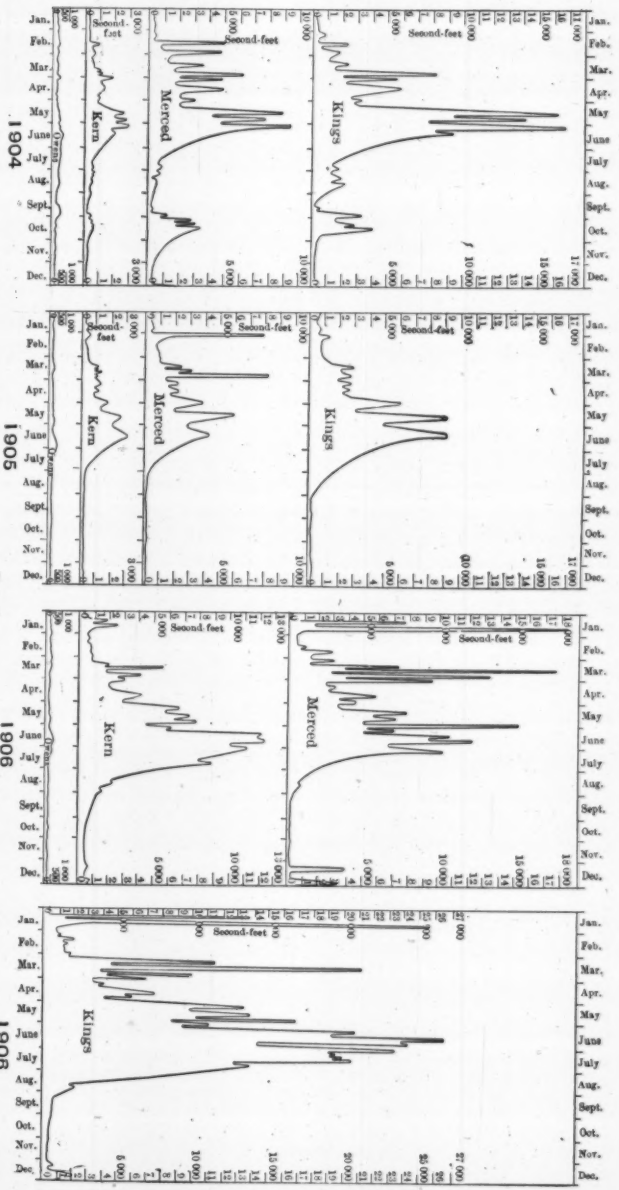


Fig. 7.

Messrs. Leffingwell and Strong.

ing a partially timbered area; and the slight fluctuation of Owens River draining a practically untimbered area.

The yearly history of the flow of these streams is as follows: The rainfall from the first storms of the rainy season in the autumn is mainly absorbed by the dry ground in the foot-hills, and causes very little fluctuation in the flow, while, on the higher levels, it forms the lower layers of the snow fields. The heavy winter and spring storms cause a heavy run-off from the foot-hills, with some of the worst floods of the year. Above about the 5 000-ft. contour, all precipitation is retained as snow. The first warm weather of summer causes melting, and about half the total precipitation is discharged in six weeks. The middle and late summer flow comes from the perpetual snow fields of the high peaks, and gradually diminishes as the weather grows colder, until the beginning of the rainy season. There are a number of thunderstorms during the summer on the higher portions of the range, but they are not heavy enough to affect the general flow of the streams. The gauging station on Owens River being at an elevation of about 5 000 ft., the winter fluctuations are not found at that point, as in the case of the others.

Tables 10, 11, and 12, record the main features of the discharge and flow of these streams, and show many interesting conditions in the resulting flow from varying drainage areas and rainfalls.

The diagram and the tables show that Kings and Merced Rivers have very similar characteristics, though the drainage area of Kings River is nearly twice as great as that of the Merced. Kern River, in all its characteristics of stream flow, occupies an intermediate position between the two foregoing and Owens River, and the latter shows the least variation of all four. An examination of the diagram and tables shows that there is a remarkable similarity between certain percentages of flow from the same drainage area for different years. For example, on the Merced River the percentage of run-off during the first 10 warm days of summer was 12% of the total discharge in 1904, 12.2% in 1905, and 11.6% in 1906, although the total depth of run-off for the same years was 20.25, 13.26, and 35.92 in., respectively. Hence this early summer run-off appears to be directly proportional to the depth of snowfall as well as dependent upon the superficial area of the snow fields. The other streams show similar regularity of similar percentages. These percentages may be considered to represent the relative intensity of the floods of the different streams, and are practically the same for Kings and Merced Rivers, less intense on Kern River, and still less on Owens River, where the run-off during the early 10-day flood period is only 4.5% of the total flow for 3 years' average. Owens River, with a greater depth of run-off than Kern River, has about half the intensity of flood.

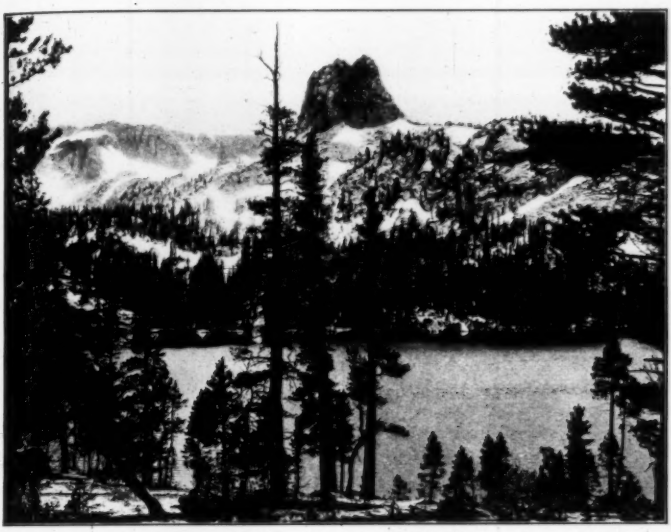


FIG. 1.—LAKE GEORGE, IN EASTERN SIERRA NEVADAS NORTHWEST OF LONG VALLEY. HEAD-WATERS OF OWENS RIVER.

FIG. 2.—EASTERN SLOPE OF SIERRA NEVADAS NEAR HEAD OF BISHOP CREEK, A TRIBUTARY OF OWENS RIVER.

TABLE 10.

Messrs. Leffingwell and Strong.

1904.	Merced River, 1 090 sq. miles.	Kings River, 1 742 sq. miles.	Kern River, 2 345 sq. miles.	Owens River, 450 sq. miles.
Total discharge, in acre-feet	1 177 412	1 880 846	492 892	208 461
Maximum daily discharge, in second-feet	May 14 8 780	May 17 15 167	June 4 3 167	June 20 635
Minimum daily discharge, in second-feet	Sept. 16 80	Jan. 21 130	Jan. 21 156	Jan. 12 152
Ratio of minimum to maximum daily discharge	1 to 110	1 to 121	1 to 20	1 to 4
Month of maximum discharge, and percentage of total	May 30%	May 34%	May 29%	June 15%
Month of minimum discharge, and percentage of total	Jan. 0.98%	Jan. 0.64%	Jan. 2.29%	Jan. 4.62%
Ratio of minimum to maximum monthly discharge	1 to 31	1 to 57	1 to 10	1 to 4
Total depth of run-off, in inches	20.25	20.26	3.93	8.78
Depth of run-off during first ten days of warm weather, and percentage of total	May 9-18 2.46 12.0%	May 9-18 2.96 14.6%	May 12-21 0.36 9.2%	May 21-29 0.32 3.7%
Depth of run-off during month of minimum fall flow, and percentage of total	Sept. 0.33 1.63%	Dec. 0.23 1.18%	Sept. 0.12 3.06%	Dec. 0.56 6.42%

From the foregoing it would appear that we should look to conditions other than the amount of snowfall or the size of the drainage basin for an explanation of the varying flood intensity. The climate on opposite sides of the range is practically the same at equal elevations. Temperature changes occur on the same dates on all four drainage areas, but their effect on the stream flow is later on Kern and Owens Rivers than on Kings and Merced Rivers.

In searching for a cause for the difference in the character of the flow from these streams, the question naturally arises as to the condition of the forest cover. It is found that the drainage areas of Merced and Kings Rivers are covered with heavy timber below the 10 000-ft. contour; that the Kern River Basin, while it has considerable timber, has large areas which are bare or covered with a light growth of

Messrs. Leffingwell and Strong.

brush; that the Owens River Basin is bare soil or rock, except where there is a narrow fringe of timber between the northwest side of Long Valley and the timber line. From this it is seen that the fluctuations of the flow in these streams bear a striking relation, and apparently a direct proportion, to the amount of forest cover over their drainage areas, the fluctuations being greatest on Kings and Merced Rivers with the greatest forest cover, and least on Owens River with the least forest cover, with Kern River as an intermediate factor in both forest cover and stream fluctuation.

TABLE 11.

1905.	Merced River, 1 090 sq. miles.	Kings River, 1 742 sq. miles.	Kern River, 2 345 sq. miles.	Owens River, 450 sq. miles.
Total discharge, in acre-feet.	771 300	1 289 000	532 100	156 600
Maximum daily discharge, in second-feet	Mar. 19 8 020	June 13 9 795	June 15 3 039	June 20 533
Minimum daily discharge, in second-feet	Sept. 25 35	Oct. 22 150	Oct. 8 175	Aug. 20 146
Ratio of minimum to maximum daily discharge	1 to 229	1 to 65	1 to 17	1 to 4
Month of maximum discharge, and percentage of total	May 27%	June 30%	June 25%	June 15%
Month of minimum discharge, and percentage of total	Oct. 0.46%	Oct. 0.82%	Sept. 2.35%	Aug. 6.64%
Ratio of minimum to maximum monthly discharge	1 to 56	1 to 36	1 to 10	1 to 2
Total depth of run-off, in inches	13.26	13.89	4.25	6.60
Depth of run-off during first ten days of warm weather, and percentage of total	May 16–25 1.62 12.2%	May 17–26 1.97 14.2%	May 19–28 0.40 9.4%	May 22–30 0.26 3.9%
Depth of run-off during month of minimum fall flow, and percentage of total	Oct. 0.06 0.46%	Oct. 0.12 0.82%	Sept. 0.10 2.35%	Oct. 0.47 7.01%

Another interesting condition of the Merced and Kings Rivers is their minimum flow. Their drainage basins, while having the maximum forest cover, give a still less absolute discharge in cubic feet per

FIG. 1.—EASTERN SLOPE OF SIERRA NEVADAS NEAR HEAD OF BIG PINE CREEK, A TRIBUTARY OF OWENS RIVER.

FIG. 2.—EASTERN SLOPE OF SIERRA NEVADAS. GLACIER AT HEAD OF BIG PINE CREEK, SHOWING CREVASSE.

second than even Owens River which has a drainage area from one-sixth to one-ninth as large, and no forest cover. Messrs. Leffingwell and Strong.

TABLE 12.

1906.	Merced River, 1 090 sq. miles.	Kings River, 1 742 sq. miles.	Kern River, 2 345 sq. miles.	Owens River, 450 sq. miles.
Total discharge, in acre-feet.	2 090 000	3 930 000	1 900 000	260 000
Maximum daily discharge, in second-feet	Jan. 19 18 400	June 20 26 600	June 22 9 505	June 25 839
Minimum daily discharge, in second-feet	Oct. 30 62	Jan. 2 205	Jan. 3 230	Jan. 8 162
Ratio of minimum to maximum daily discharge	1 to 297	1 to 129	1 to 41	1 to 5
Month of maximum discharge, and percentage of total	June 24%	June 26%	June 24%	July 16%
Month of minimum discharge, and percentage of total	Oct. 0.36%	Nov. 0.59%	Nov. 1.59%	Feb. 4.38%
Ratio of minimum to maximum monthly discharge	1 to 67	1 to 44	1 to 14	1 to 4
Total depth of run-off, in inches	35.92	42.26	15.18	10.97
Depth of run-off during first ten days of warm weather, and percentage of total	June 16-25 3.98 10.6%	June 16-25 4.98 11.8%	June 15-24 1.46 9.6%	June 20-29 0.64 5.8%
Depth of run-off during month of minimum fall flow, and percentage of total	Oct. 0.13 0.36%	Nov. 0.25 0.59%	Nov. 0.24 1.59%	Nov. 0.60 5.47%

The present intention of the Forestry Bureau to plant forests on a large portion of the Owens River drainage area would seem to be unwise, in view of the foregoing conditions. This is particularly true as this stream is the intended source of the water supply of Los Angeles, and at no very distant day every drop of its water will be carefully hoarded.

Plates XLIV and XLV show the snow fields of the upper levels of the Owens River drainage on the east side of the Southern Sierras. Particular attention is drawn to the fact that all snow has melted from under the trees or around them and only remains in the drifts in the bare areas between the clumps of trees.

Mr. Willis. BAILEY WILLIS, ESQ. (by letter).—Four propositions are stated by Colonel Chittenden, and his argument is devoted chiefly to proving that they are not true. The writer holds that they are essentially true, provided that the limiting conditions, such as modify any general case, are appropriately considered. These propositions will be considered in order.

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(1) By storing the waters from rain and melting snow in the bed of humus that develops under forest cover, preventing their rapid rush to the streams and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off."

Forests do have a beneficial effect, although their capacity for such effect is not unlimited; neither are they in every location the most effective means of regulation. It is important to distinguish between level or very gentle slopes and steeper slopes, particularly those of mountainous districts. On the level, a forest-covered area and a well-tilled field compare closely in their capacity to absorb rain, but the forest prevents from 20 to 40% of the rain from reaching the ground (according to density of foliage, kind of trees, intensity of storms, and other conditions), and it transpires a large amount of moisture. Consequently the bare level field nearby receives more rain, and contributes more to ground-water. It also evaporates less than the forest transpires, and consequently it retains more from the same rain than the adjoining forest. The statement quoted from Mr. Zon* is strictly correct, as is shown by the experiments cited by Ernst Ebermayer,† who sums up the case as follows:

"In view of the exact investigations which have been cited above and which extend through 30 years, it is no longer possible to maintain the assumption so generally made, that forests increase the amount of ground-water, and constitute a storage reservoir for the supply of springs, at least not so far as plains are concerned. The draining effect of the forest is, on the contrary, so great that a much greater supply of water gathers in the depths beneath a treeless plain than beneath dense woods, provided that the underground conditions be the same in both cases. It follows that under these conditions the discharge of springs is not increased, but lessened by woods. Decided emphasis must, however, be laid upon the fact that these conclusions hold primarily only for the plains, and are not to be extended inconsiderately to uplands and mountains.

"Although the influence of the woods upon soil, moisture, percolation, and ground-water, under like soil conditions, must be the same in mountains as it is in lowlands, and only moderate differences are likely to appear, nevertheless the forest on the mountain differs very decidedly from that on the plain in regard to water control, inasmuch

* Page 251.

† Einfluss der Wälder auf die Bodenfeuchtigkeit, auf das Sickerwasser, auf das Grundwasser, und auf die Ergiebigkeit der Quellen, 1900, page 88.

as in mountain regions, in consequence of the surface run-off of rain and snow water from the slopes, a factor is introduced through which wooded mountain slopes receive a much larger amount of water than bare unwooded water-sheds." Mr. Willis.

Any one who will examine the data, derived from 30 years of observation and experiment, on which Ebermayer bases his conclusion, will hardly think that "*post hoc, ergo propter hoc* is the argumentative process relied upon."

The question of regulation of floods from mountain valleys by forests cannot be allowed to pass without a discussion of Colonel Chittenden's argument. In assuming "an inclined-plane surface, practically impervious to water," he introduces a special condition that may arise under a forest, but only as a limiting case, namely, when the forest has stored all the water possible and can do no more. On slopes which facilitate run-off, no other agent can do as much.

Contrasting the division of rainfall on forest slopes with that on bare slopes, there is, in each case, water which is lost to use, a minus quantity, and water which is gained for use, a plus quantity. The loss on the forest slope is: (1) That which stays in the tree tops; (2) that which is held by litter and evaporated from it and from the soil; (3) that which is transpired through roots and leaves. The loss from a bare slope is evaporation plus run-off. The gain in either case is through percolation and ground storage for a longer or shorter period.

During a period of little or no precipitation, the chief loss from the forest is by transpiration; on the level, as determined by observation in Russia, France, and Germany, it is greater than that by evaporation from a bare surface, and lowers the water table relatively to that in an adjoining field; on mountain slopes, it no doubt has a similar effect, which is, however, in considering the losses from forested slopes, to be balanced against quick run-off from bare hills. At the end of a dry period the ground reservoir beneath the forest, on plain or mountain, is in a condition to receive more water than that beneath a bare slope.

During a period of precipitation the chief loss from the forest is in the tree tops. As already stated, it varies greatly in amount, but, whatever it comes to, it is, in the limiting case of an excessive rain, a beneficial because a minus quantity.

At the end of a dry period, the layer of leaves, rotten wood, and humus beneath a forest has a capacity to absorb as much as 50% of its volume of water. When rains come, this amount is retained from run-off or ground storage and later evaporated. So retentive is the humus that, while it serves as a sponge to prevent run-off and transmit water to the ground reservoir, it does not give up much to storage, and yields its water-content only slowly to the moderate influences of

Mr. Willis. evaporation in the shade. The amount thus retained is small as compared with that which is transmitted through wet litter to ground storage, but it is an amount which can be controlled by regulating the litter. The proportion of precipitation absorbed by forest litter, therefore, need not be an injurious minus quantity if the water is wanted in the stream; but it is a beneficial minus quantity when there is more water than can be handled. The algebraic sum of these opposite results depends on climate, topography, and water service, and, under conditions of good forestry, determines what proportion of litter shall remain beneath the trees, and to what extent measures shall be taken to substitute an open soil for it at the surface. He reasons without thought who reasons without reference to forestry in regard to forest conditions.

Thus considering the limiting case of great precipitation, it must be recognized that the forest on a slope holds back the most water, unless it can be shown that percolation into a bare slope exceeds loss from tree tops, loss in the forest litter, if any, and percolation into the ground under the forest. There are cases where percolation into bare ground on a slope reaches this surprising proportion, as on sand hills, and on some very coarse granite soils of equally open texture; but it does not reach this proportion in loams and clay soils; on the contrary, on these quick-spilling soils, percolation is a very small part of precipitation.

Statistics of comparative run-off from bare and forested slopes, which are observed in such a way as to yield data for close comparison, are not known to the writer. It is probably safe to say that they have not been observed in the United States. To obtain them, one must observe the same precipitation on adjoining areas, of like slope, soil, and geological structure. Only in this way can the forest influence be isolated, and its effect ascertained statistically. The writer, however, has before him the results of three years' investigation by Professor L. C. Glenn, of Nashville, Tenn., in the Southern Appalachians, the most critical region of the United States, and has gathered from Professor Glenn's manuscript report to the Forest Service the following summation of details which bear on this question.

Forty-six creeks and small rivers, the water-sheds of which may be described as timbered rather than cleared, are known, according to observation and local repute, to rise gradually in times of flood, to continue high for several days, and to subside slowly. They carry but little sediment, and they maintain a good volume of water during dry seasons.

Thirty-eight creeks and small rivers in the same water-sheds, having slopes which may be described as cleared rather than timbered, are known, according to observation and local repute, to rise rapidly in times of flood to extreme flood height, to carry excessive quantities

of mud, sand, and gravel, and to fall quickly. In dry seasons they are very low, and the range from lowest to highest stages has increased, and has inflicted much damage in very recent years. Mr. Willis.

Two other classes of conditions may be recognized in Professor Glenn's descriptions: One, of valleys which are still timbered, but which are being damaged by the commencement of logging operations, and particularly by the erosion of logging chutes; the other, of water-sheds which are largely cleared, but grassed, and which the grass protects from erosion, though not in the same degree from rapid run-off.

Such evidence as this, collected by a qualified and impartial observer, with reference to individual water-sheds, establishes, for the region in question, comprising the mountains of North Carolina, Tennessee, and Georgia, the fact "that forests do exert a beneficial influence on stream flow by storing the waters from rain and melting snow, preventing their rapid rush to the streams, and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off."

As compared with these direct observations on limited water-sheds, the statistical data of precipitation and run-off on large streams, as presented by Colonel Chittenden, have a minus value for consideration of the question at issue. The stations of the Hydrographic Service and of the Weather Bureau are too few in number and too widely scattered. The method of analysis does not take account of the great diversity of conditions in an extensive water-shed, to which Colonel Chittenden calls attention.* Engineers know that a circuit of approximate observations may be run and close fairly well if the number of observations be sufficiently large, the result being the mean of many balancing errors; this is also true in the observation of flood stages or low-water stages, on the Ohio, for instance. In any case the stage is a mean of balancing conditions on hundreds of small water-sheds, some of which are forested and some deforested, some of which are and some of which are not cultivated. In that mean, the effect of the individual water-shed is so obscured as to be quite indistinguishable. Conclusions based on inferences from such data have not the value which they should have, in order to carry weight with the engineering profession.

Colonel Chittenden, further, says:

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(2) By retarding the snow-melting in the spring and prolonging the run-off from that source."

In regard to the influence of forests on melting snow, Colonel Chittenden argues "that the effect of forests upon the run-off from

* Page 249.

Mr. Willis.

snow is invariably to increase its intensity. This results from two causes, one affecting the falling of the snow and the other its melting."

Following Colonel Chittenden, snow which falls in the open may be divided into that which remains evenly spread and that which is gathered into drifts; and snow which falls in the forest may be divided also into two parts, namely, that which reaches the ground and that which hangs in the branches. The snow which is held back in drifts and that which is hung up in the branches of the trees and returned to the air by evaporation may be said to be withdrawn from immediate run-off. The statement is not quite correct in either case, but the qualifying considerations are not such as to modify the balance which may be roughly struck between the two quantities, when each approaches a maximum. There remains in the open an uncertain but large proportion which is melted, as all agree, early in the spring, and there remains in the forest a considerable proportion which is held in the protection of the trees until later in the spring and early summer. From any such snow-covered region of moderate altitude, we commonly have spring floods, which are produced chiefly by the melting of the snow in the open, both from the areas that are evenly covered and from the surfaces of the drifts, and subordinately by a contribution from the snow that is melting more slowly under the trees. Were all the snow in the open, the proportion which would be contributed as run-off to the early spring floods would be much larger, and these floods would be much more disastrous. Later in the season, the forested parts of such regions sometimes occasion severe floods in consequence of a large body of snow lingering until the warm winds strike it. This effect is undoubtedly unfortunate, but the question may well be asked whether it were better to have the June flood on top of that of April, rather than divided, as they are likely to be in consequence of the presence of the forest. The condition is one in which excessive precipitation results in run-off which is beyond the control of any natural agency, and high waters will ensue whether or not there be any forest.

In the Northwest there is a special condition prevailing on the higher ranges which rise above the tree-line and even into the region of perpetual snow, a condition which is described by Colonel Chittenden, and has the effect that he regards as general. The writer is familiar with it in the high mountains of Western Montana, Idaho, Washington, and Oregon. The deeply sculptured crags and peaks of the mountains above the tree-line produce such eddies in the strong winds, that a very large part of the heavy snowfall is gathered into drifts. At these altitudes even "chinook" winds are cooled by expansion as the air currents push upward along the mountain sides, and they melt less snow than on lower slopes. Therefore the drifted snow banks linger far into or through the summer, continuously feeding

the lakes and streams. The special condition is one of incipient glaciation. From the glaciers of Mount Rainier one may learn what happens when this condition develops extensive bodies of ice and snow, and Colonel Chittenden has kindly furnished an illustration—that of the White River (Fig. 1, Plate CX). This particular White River flows from the Emmons and White River glaciers which cover the eastern and north-eastern side of Mount Rainier, and its well-earned character of a bad stream is due to this fact, and not to the forest which once densely covered its lower course, but which is now severely cut and burned. Colonel Chittenden is unfortunate in not being acquainted, apparently, with the real character of the river. The writer was well acquainted with it at one time; he spent four years in these forests before they were touched by axe or fire (1881-84), and became familiar with the glacial and non-glacial streams by personal contact. The former are subject to well-known daily fluctuations, rising in the morning and falling at night; the writer preferred to wade them early in the day. They also rise sharply under warm winds, and fall quickly when the air is chilled. The non-glacial brooks were uncompromisingly high and comparatively steady day and night, from some time in March until the snow was gone from under the forest cover. Mr. Willis.

Thus the writer's conclusion, based upon experience of snow conditions ranging from the mountains of North Carolina to the glaciers of Mount Rainier, is that the forest does exert a beneficial influence in retarding the melting and run-off of snows, even though, as happens in certain areas, the snowfall is so great as to produce floods in spite of the forest's influence.

Colonel Chittenden maintains that:

"In periods of extreme summer heat, forests operate to diminish the run-off, because they absorb almost completely and give off in evaporation ordinary showers which, in the open country, produce a considerable temporary increase in the streams."

This fact, regarding the influence of forests upon light summer showers, might have been supplemented and the argument strengthened by stating that during the hot seasons forests also transpire a large amount of water which is taken from soil moisture, and these two facts together set a limit to the value of forests in regions of meager rainfall. For instance, it is established by experience on the Great Plains, as well as in the orchards of Southern California, that wind-breaks may take more moisture from the soil than the crops near them can afford to lose, and the effect on the crops would be the effect on any spring in equally close proximity; but against this demand of the plant for moisture to carry on its physiological processes, must be set the contribution which it has made at an earlier season to ground-water storage in excess of the contribution which would have resulted from bare ground. Here again recurs the question of slope and the

Mr. Willis. proportion of run-off, and it must be recognized that, in the semi-arid plain, narrow limitations are placed upon the advantageous growth of trees, which do not hold for the mountains under humid conditions. There, more water is stored by the slow-spilling surface and retained by the ground under the forest than by that under the quick-spilling slope of bare ground. The stored water in the ground is the principal source of low-water supply, and thus, in times of precipitation, the forest performs a service which inures to the advantage of low water in times of drought.

The ideal condition for ground-water storage, in order to maintain stream flow, is an even plain covered by a receptive soil, that is, by a soil which is in the best state of preparation for growing crops. Such a soil is maintained by deep plowing, by culture during the growing season, by keeping the fallow ground broken up, and by crop rotation; that is, by methods which increase the productiveness of the fields. The one essential condition, however, to make this surface more retentive than a forest-covered surface, is that it shall be so nearly level that run-off will not be a notable factor. To establish this condition on gentle slopes, the farmer may resort to contour plowing and harrowing, but to establish it on steep slopes, it is necessary to build terraces. All the older nations of the world have had to build terraces in order to extend the cultivated areas far enough up the mountain slopes to supply, in some measure, the demand of growing populations for food. We are still a long way from that condition, but nevertheless it should be recognized that terraces have a place in systems for the conservation of waters for city supply, power, or navigation. In a region where the conditions are so difficult and so critical as they are in the Southern Appalachians, farming should be carried on only as far as terracing can be adopted economically. Beyond that area, wherever terracing would be so costly as to prohibit farming, the surface should be covered with a vigorous forest.

The writer cannot leave this subject without commenting on the oft-repeated statement that natural re-forestation restores the conditions of water control, which existed under virgin forests. No one will deny that natural re-forestation is a general result of the initial cutting of the forest. No one can reasonably affirm, however, that the second growth which springs up behind the American lumberman possesses the character of the virgin forest. Its roots are weaker, its branches afford less protection, and its influence upon water storage is different. In some cases, the young forest being more open than the old, and its demand for water less great, a larger proportion of water will appear in the springs, and the rivers will run fuller for a time. This is particularly true of the densely forested ranges of the Northwest, and Colonel Chittenden cites a special case

in a region of moderate rainfall and porous soils (Nevada), where this effect was a maximum before the new growth used much water. If the young forest were vigorous enough and could be given time enough to grow to the stature and density of the old stand, it would eventually re-establish the conditions that existed under the virgin forest; but in any case, during the growth of the young forest, even under the best conditions, erosion has begun its insidious work. The gully that is cut in the forest cover may be but a few inches deep, or, as frequently the case in the Southern Appalachians, many feet deep; it may be covered by logs, brambles, and weeds; but it lowers the level of discharge by a corresponding amount and gains an advantage for attack upon the entire slope. That advantage it never loses, and the effect is the removal of the superficial soil at first and ultimately of all the soil which is above the level of discharge of the mouth of the gully. Though this ultimate effect be deferred for a long term of years, it will certainly be reached. In the high mountains one has only to climb the crags above the tree-line to see the result. In the Southern Appalachians, where the soil is decomposed rock, of impervious texture and great depth, one has only to consider the logging chute and the old field. There, from virgin forest to abandoned field is frequently an interval of but five years, and, while it is true that the farmer has a worse record than the lumberman, the difference will not be material fifty years hence. In China, where the precipitation is much less and the conditions, consequently, less favorable to erosion, the writer has seen several thousand square miles of mountainous country like the Appalachians, which has been completely deforested, denuded to the bare rock, and depopulated, in the last century and a half. There is great reason to protest earnestly against any superficial observation which leads to the conclusion that no harm is done by reckless lumbering and ill-judged agriculture, because Nature with her wonderful recuperative power in some measure conceals the scars. Mr. Willis.

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(3) By increasing precipitation."

In opposition to views which are frequently supported by general rainfall statistics, and are endorsed by Colonel Chittenden, the writer holds that forests do affect precipitation; that they increase it slightly over that which falls upon green fields, and that they increase it notably over the amount received by bare plains under critical atmospheric conditions. He holds that these relations may be perceived over sufficiently wide level lands, but that they are particularly perceptible in the case of mountain ranges. More important, however, is the influence of the forest or rock of a mountain range, because there the

Mr. Willis. effect of deforestation is to increase conspicuously the irregularity of precipitation.

The principle which underlies the effect of forests on precipitation is very simple. Moist air currents rising into the upper strata of the atmosphere are dilated and cooled. Their vapor is condensed and falls as rain. Any effect which increases the proportion of moisture and lowers the temperature promotes precipitation; any effect which decreases the proportion of moisture or raises the temperature lessens precipitation.

It has been shown that forests transpire more water than is evaporated from the bare ground, and the experiences of balloonists, particularly in France, show that the air is cooler over a large forest, even at a height of 1 500 m. Sometimes, over hot plains, a shower may be seen to begin to fall, but to evaporate before it reaches the ground. While these effects are certainly subsidiary to the great movements of moisture along the cyclonic tracts from the west and south toward the northeast across North America, they cannot be said to be negligible.

Man cannot readily change a great plain from a forested region to one bare of soil, and when he substitutes for the trees a vast stretch of grain, as has been done in the Upper Mississippi Valley, he does not change the conditions of radiation so seriously as to affect the powerful rain-bearing currents which sweep up from Texas and the Gulf. The case is entirely different, however, in regard to mountain ranges. It is easy, with the aid of the rills and torrents, to remove their covering of vegetation, and they can be denuded so completely that the radiation from bare rock replaces that of forest for an entire mountain range. The precipitation over mountains is always less regular than that over plains, for the irregularities of the mountain slopes cause the air-currents to rise and expand and cool very unequally; and when these conditions are exaggerated by removing the regulating effect of the tree surface and by substituting the aggravating effect of the bare surface, conditions are produced that result in more violent floods and more excessive drought than existed before Man did his irrevocable work.

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(4) By preventing erosion of the soil on steep slopes * * *"

It is difficult for the writer to understand how any observer can say, as Colonel Chittenden does,* that there is a deficiency of evidence to support this view. As a geologist, the writer's attention has been constantly drawn to the evidences of erosion under the varied conditions of relief and climate in nearly all parts of the United States

* Page 270.

and also throughout Europe and not a small part of China. There is, according to his observation, a definite relation between the different valley deposits and forest-covered hills on the one hand or denuded hills on the other. He cannot recall an exception to the fact that streams flowing from hills which have been denuded of forests have filled their lower valleys with broad flats of sand and gravel through which the waters meander in shifting, uncertain channels. Equally closely related are forested mountains and clear streams, which flow through valleys with well-established channels and more or less extensively developed flood planes that are covered with appropriate vegetation. Mr. Willis.

In all regions where precipitation is sufficient to maintain a forest cover, a certain equilibrium is reached between the rate of soil production and soil erosion. Streams of a certain size, on a certain slope, are able to keep their bottoms clean and slowly to erode them. Less efficient rills are unable to penetrate the protective cover and cannot effectively begin the task of corrasion. This limit varies according to climate, vegetation, and soil conditions, and is not the same throughout any one district, much less in regions so different as the Appalachians and the Cascade Mountains; but wherever virgin forests have persisted during a geologic age, as they have over a great part of the United States, the processes of Nature have brought about the adjustment, and have reduced the progress of erosion to a slow rate.

This adjustment is gravely disturbed when Man cuts a forest. No material damage need ensue if he does so intelligently and protects the surface until vegetation can recover from the relatively slight injury that is done by forest cutting under good methods; but the methods of the American lumberman, followed by fire, as they too often are, result in such a disturbance of the adjustment as to make recovery extremely difficult, even if possible.

The effect of the disturbance is seen in the vigorous growth of thousands of little gullies, which are scarcely noticeable at first, but which grow like the branches of a tree, and spread far out into the previously uneroded surface. Vegetation always makes a brave fight, but unless aided by Man it can never recover the position which it originally held.

As stated by Colonel Chittenden, Man too often does not aid vegetation, but carelessly establishes fresh channels of erosion in wheel ruts, logging chutes, etc.; he cultivates the ground under conditions that promote the gathering of the rills and the washing of the soil. Thus, he proceeds with criminal negligence to accelerate the process which, if continued, will eventually make such districts as the Appalachian Mountains uninhabitable.

Any one who takes a broad view of this vital question of the

Mr. Willis. control of the waters in their circulation over and through the land must recognize that the forces of Nature, involved in rainfall and sunshine, in the quiet stream and in the great flood, can be regulated and brought to serve Man, but only through the co-operation of all the forces that he can bring to bear. The farmer who before long will cultivate more than one-half of our country, the herdsman who will graze his flocks over one-fourth, and the forester who, to supply our needs, must raise his crop of trees on one-fifth, must all co-operate to control the Genii of the waters. The opportunity to make them our servants is where we can turn them from the paths of the air or the channels of the rills to the dark courses underground in the recesses of the rocks. Every method of agriculture, grazing, and forestry must be used to promote ground storage and reduce run-off. Even then there will remain a certain surplus of flood waters, the immediate gathering of which cannot be prevented. These and all other waters that join in our rivers in their course from the mountains to the sea, must be committed to the care of the engineer, whose duty it is to store, to divert, to regulate them, so that they shall be made to serve every purpose to which civilization can put them.

Mr. Leighton. M. O. LEIGHTON, ASSOC. M. AM. SOC. C. E.—This paper is so admirable a literary composition and so persuasive in its presentation that one is well-nigh beguiled into acceptance of the author's precepts. It is only after critical review and the application of fundamental principles that one is prepared to appreciate how erroneous are the premises, how mistaken the deductions. Such a consideration reveals several points of peculiarity, which may be summarized as follows:

1. A large number of the premises and observations on which the author's conclusions are based are in error;

2. Nearly all his difficulties with reference to the relation of forests to stream run-off would be solved if he had not misconceived certain fundamental principles;

3. In the progress of his argument he presents contradictory views;

4. He rejects many generally accepted ideas, because little or no evidence has been brought forward in their support, and then he substitutes concepts of his own without any accompanying demonstration.

An attempt will be made to reveal all these peculiarities in the following discussion. No effort will be made to treat them in categorical order, because such is not the prime purpose of this rejoinder. The points will be indicated incidentally in the discussion of the principles involved.

At the very outset there is revealed a fundamental misconception which largely explains many of the adverse deductions in relation to

forest control of run-off, viz.: "By storing the waters from rain and melting snow in the bed of humus that develops under forest cover, preventing their rapid rush, * * * ." If this means strictly what it says, the author believes that the bed of humus is the agent of storage. The impression here conveyed is intensified by the practical illustration given under the caption "Effect of Forests Upon the Run-Off from Rainfall," in which an inclined-plane surface is used, "practically impervious to water, with a layer of sand covering some small portion of it." The author has forgotten the greatest reservoir, namely, the ground. When he assumes an inclined-plane surface, impervious to water, he denies the existence of ground storage. The speaker has never before heard the principle of forest cover so applied. The common understanding is that the forest mulch is not the storage agent in any except a merely nominal sense. Its whole function is to protect the ground, so that its surface will not become hard and impervious, and to conduct the water of precipitation into the interstices of the underlying soil. The effects of this fundamental misconception are apparent in many parts of the paper, and, in fact, the whole argument relative to the inefficiency of forests in conserving water is based upon it. Were the author's original conception correct, then indeed would his conclusions have a measure of justification, but not otherwise. Mr. Leighton.

Although Colonel Chittenden denies that there is a pervious soil under the forest, he readily grants that there is a marked retentive capacity in bare soil. The reader must infer, either that there is no soil under the forest, or that soil covered by forest must in some way remain impervious. The really fatal admission, however, is in the sentence: "In newly plowed ground it (the retentive capacity) is probably greater than in the forest." There is a reason why newly plowed ground is, as the author implies, more retentive than unplowed, bare soil. This reason is that the compacted surface crust has been broken, the underlying earth has been disturbed and loosened, and thereby made absorbent to the precipitated water that falls upon it. After the rains have descended, and the sun has shone on this plowed ground for a period, a compact surface is gradually formed. The result is that the water is less easily absorbed and the retentive capacity of that particular piece of ground constantly decreases, as the date of plowing recedes.

What now is the effect of the forest-mulch cover? It protects the ground from the direct pelting of the rain and the resulting process by which the earth's crust becomes compact, and keeps it in a condition that is always equivalent to that of a newly plowed field. No one who has ever scratched away the mulch cover in a forest can deny this. The earth below is always found in an open and porous condition. How, then, can the retentive capacity of a newly plowed field be

Mr. Leighton.

greater than that of the soil beneath the forest, provided, of course, the two soils are of the same character? With physical conditions identical, the retentive capacity must be the same; but, when one recalls that the forest mulch must assist in this absorption by retarding the water that would otherwise run over the ground, the superiority of forest-covered soil for modifying run-off would seem hardly to be susceptible of more complete demonstration. It is readily admitted that there are some soils which, even under forest cover, will not retain as much of the precipitation as some others which are kept bare; but, in making comparisons of this kind, one is assuming, of course, that the conditions are comparable. It is assumed that the soils are the same in point of texture and retentive capacity. In the beginning of his paper Colonel Chittenden implies that the soil beneath the forest must be impervious. Later, in the paragraph quoted, he implies that it may be somewhat pervious, but not to as great a degree as the soil unprotected by forests; all of which indicates that the original conception, as well as the deductions, are unfortunate, from his point of view.

In the pursuit of his argument, a contradiction is presented.* The regulative effect of the forest bed in moderate storms is clearly admitted. It is then stated that, by reason of later and heavier storms, this forest bed gives up what it had originally retained. Of course, the forest bed does not store the floods, as the author claims, and equally, of course, it does not prolong the run-off after the storms have passed, this being the function of the great ground-storage reservoir; but, assuming for purposes of illustration that his contentions are true, how can it be possible that this forest mulch may contribute to a later flood, and produce a devastation greater than would occur if the area had been bare? Assume that a rainfall has occurred, which has just saturated the forest mulch, and that it can store no more. Let a later and heavier rain follow. Is not this forest mulch going to retain its retentive capacity, irrespective of later rains? If so, how is it possible that merely by reason of a later rain the forest mulch is going to shed all that later rain and, in addition, the water which it had received from the previous rain? Under such a conception, the second rain must have an effect of desiccation on the mulch. If the contention were that the forest mulch would have no effect on the run-off from the second rain, admitting for the moment that the author had not misconceived the fundamental idea, then his conclusions would be justified; but, in order to contend that this forest mulch is going to increase the flood, the assumption must be made that it will give up gratuitously that which it had previously collected. It is hardly likely that so able a man as Colonel Chittenden will, on taking thought, subscribe to such an assumption.

* Page 249.

Mr. Leighton.

The paragraph on pages 250 and 251 contains another contradictory statement, and presents certain new concepts, unsupported by supplementary evidence. The first sentence is an admission that, in periods of extreme drought, springs and little streams dry up more completely under deforested than under forest conditions. It is then stated that the difference is exaggerated in the popular mind. On the contrary, it is very doubtful if the difference between the two conditions could be exaggerated. One could hardly exaggerate a difference between flowing water and a dry spring or rivulet. The margin must be 100% in all cases. The exception noted by the author in the foot-note,* with reference to the drainage of low swamp lands, while true, has not even a remote relation to the conditions under discussion. The drainage of a swamp area is essentially the tapping of a reservoir. It bears the same relation to spring and rivulet flow as would an artificial storage reservoir. The water released during dry seasons must prolong the flow, of course, whether the release be effected by raising a gate or digging a trench. The author then states that, because springs and streams are dried up, there is no reason why there should be any appreciable diminution in the flow of the great river. This idea is strange and new, and brings up a question as to the sources of supply in a great river during a period of extreme drought. No one can well deny that rivers are supplied during such periods from ground storage, which collects almost entirely in the small streams and rivulets, and unites ultimately to form the great river. The immediate drainage on any great river, which contributes seepage directly to the main artery, is always comparatively small and sometimes negligible. Why, for example, has there been any water whatsoever in the Ohio between Pittsburg and Cairo during the summer and fall of 1908? No one believes that, had the immediate drainage area contributing to this main artery been depended on, the Ohio channel would have been anything but a dry bed. The supply that has been contributed to this river has come from the millions of small rivulets, each of which has drawn on its immediate ground storage, and, by uniting, has formed the brook which, also drawing upon its immediate storage, has formed the larger tributary, and these, supplemented to some extent by immediate ground storage, unite to form the river which, in spite of the lack of rain, has persisted. In other words, the great ultimate sources of supply for any river lie in these small rivulets, and the discharge of any river is but the result of their union. This is a matter of elementary physiography, long ago enunciated, repeatedly confirmed, and, as far as the speaker knows, undenied up to the present instance. Admitting, therefore, the truth of the proposition and, in view of the author's admission that springs and rivulets dry up more completely under deforested than under forest conditions, what becomes

* Page 250.

Mr. Leighton. of the contention that forests do not sustain stream flow during dry seasons?

It is of interest to pursue further the author's reasoning. He contends that if all these small rivulets become dry the river will nevertheless, somehow, somewhere, get its water supply. Moreover, the conception implies that the normal supply of water in these rivers must appear suddenly, as if in response to the smite of Moses' staff. If the course is followed, it will lead out of dry rivulets and brooks into a normally flowing stream. The transition from dry conditions to those of normal flow must be abrupt. Whence comes this providential supply? The facts are that the drying up of springs and little streams means simply that the ground storage has been drawn down or exhausted. The concept of the author is hopelessly involved. Between his admission of dry springs and little streams, and his assumption of normally flowing rivers, his argument is ground to pieces, as it were, between the upper and the nether millstones.

The author further states that heavier showers, which make freshets in the open, are largely "absorbed in the leaves and forest bed and pass off in evaporation." This concept is advanced without demonstrated proof; how does the author know that this is true? The demonstrated facts are all to the contrary. The showers which, falling in the open country, make freshets, must, when they fall on the forest, pass through the "leaves and forest bed" and enter the ground, merely because they have the opportunity, which opportunity is largely denied them in the open. The water which is absorbed in the leaves and forest bed from heavier showers is but an insignificant part of the total precipitation.

Further along it is stated that it is better to have a good than a uniform flow in a river. It is difficult to imagine how one can be attained without the other. In order to have a good flow, it is necessary that the low extreme be prevented, and this very prevention means comparative uniformity. Good flow (and by this it is assumed that the author means abundant flow) is attained quite as much by the prevention of low periods as by the production of high ones.

The final sentences of the paragraph* enunciate a curious doctrine. It is stated that "great rivers swallow up and equalize the small irregularities of their head-waters and actually experience somewhat larger low-water flow than if their water-sheds were still thickly forested." This is not uniformly borne out by experience; but only the logic of the argument will now be considered. If it be true that the source of supply of great rivers is ultimately in the small rivulets, how is it possible, with lack of uniformity in those small rivulets, to secure uniformity in the large ones? Of course, if the lack of uniformity took place in successive periods over an entire drainage area,

* Page 251.

there might be uniformity in the stream below, because, after one small unit of the supply had exhausted itself, the next would supply the deficiency, and so on to the end; but, as the author forcibly states, natural run-off cannot be controlled with such mathematical accuracy. Uniformity in small rivulets begets uniformity in the main artery supplied by those rivulets. The cause and effect are so clear as to become axiomatic. If, as the author contends, deforestation assists in the drying up of springs and rivulets, then, as a necessary consequence, the flow of the main affluent must become less, and the effect will be more and more pronounced as the proportionate amount of deforested area decreases, until finally, when there is absolute deforestation, there must be this tendency of small rivulets and springs to dry up over the entire area. If the author would give consideration to the all-important matter of ground storage and apply thereto some of the fundamentals of geology and physics, he could readily see the fallacy of his argument. Mr. Leighton.

With reference to the section concerning the influence of forests on snow-melting, it appears that the author's observations have been confined to a comparatively limited area in a high altitude. Several of his observations are faulty for the areas which he is considering. He has apparently neglected all consideration of the physical principle of diathermancy. His premises will be considered in their order of presentation.

The statement that forests prevent the formation of drifts, and distribute the snow in an even blanket over the ground is, of course, quite erroneous. Every country boy has floundered through drifts in the forest, and Dr. George Otis Smith, in his discussion on this paper, testifies that in the very region concerning which Colonel Chittenden appears to be most familiar, and in the same year in which the latter made some of his observations, his (Dr. Smith's) horse became stalled in a snowdrift in a dense forest on or about July 1st. Further, the author states that, "in the open country, the snow is largely heaped into drifts," which is quite as erroneous as the first statement. On the tops of peaks and in extremely high altitudes, constantly subject to great winds, this may be true at times; but it is certainly untrue for the greater part of the country, the quantity of snow in the drifts being but an exceedingly small part of the total accumulation. Even in high altitudes, the heavy and uniform blanket of snow is common, as can be shown by hundreds of photographs on file in the Geological Survey.

Consider this, together with the author's admission that the period of snow-melting in the open country begins much earlier than in the forest; and consider further the well-known physical fact that the melting of snow takes place at the bottom and not at the top, except, of course, in the event of warm melting rains. This is a point

Mr. Leighton.

entirely overlooked by the author. The blanket of snow in the open, not heaped into drifts, melts first, and the water naturally seeks to percolate into the ground. Bare soil will not absorb this water to the maximum extent. In many cases, in northern latitudes, the surface is frozen before the snow falls upon it, and it thereby becomes practically impervious. The first rush of melted water goes directly into the streams and, as it is a quick melting, as Colonel Chittenden contends with so much truth, it follows that there must be a gorging of the rivers. Now, of course, these freshets would be considerably less if the greater part of the snow were concentrated into drifts, as claimed by the author; but, inasmuch as over the greater part of our snow-covered country this is not the case, the saving element does not apply. Consider now a drainage area, one half bare and the other half forested, and apply these principles to it. The snow covering the ground in the open, exclusive of drift, melts rapidly and rushes into the watercourses, filling them to a certain height. With this in mind, assume that the forest has been removed, and that the whole area is bare; does it not follow that, where formerly the 50% bare country contributed its melted snows to the river channels and filled them to a certain height, 100% of the same area would fill them to a greater height, or, in fact, would practically double the discharge? Under the forest condition, there is a division of floods. One-half the area would discharge its flood-waters, and then subsequently the other half, which is quite different from the condition in which the whole area discharges practically simultaneously.

In the foregoing assumptions liberties have been taken with facts concerning forests. It has been assumed that, while the melting is going on in the open, none is taking place in the forest. This is not true. By diathermanous effect, the sun's rays, which, according to Colonel Chittenden, melt the snows in the open, begin to melt the snow in the forest quite as early, the difference being that the forest melting is much slower. And what takes place there? The layer in the forest begins to melt at the bottom. Beneath it is not a compact and frequently frozen layer of ground, but a litter of mulch, and beneath that an open, porous soil, protected from the early winter cold which freezes the ground in the open. The forest litter conducts this melted snow into ground which is eager to receive it; but Colonel Chittenden cites the fact that later warm rains will hasten this melting. This is true, but why confine this effect to the later warm rains? Early warm rains are not uncommon. When they fall over the snow on the open land, would not the effects be even greater than in the forest? The author then contends that the snow in the open is melted by the rays of the sun before the air has become warm. However true this may be in high altitudes which he cites as examples, one must know that it is not true in the lower altitudes. The

severest floods which have been experienced have been caused by warm rain falling upon hitherto unmelted accumulations of snow. In the lower altitudes warm rains sometimes occur in midwinter. They fall "on the just and on the unjust," on forested as well as on deforested areas, and if Colonel Chittenden's reasoning be correct, then would the melting in the open be much faster than in the forest. Mr. Leighton.

It is true, as Colonel Chittenden states, that a drift in the open in the high Sierras and Rocky Mountains remains long after the snow in the forest is gone. There is a reason for this, which is peculiar to such country. This is not always true in the lower countries, Colonel Chittenden's experience in Western New York to the contrary notwithstanding. Inasmuch as the author has referred in an attractive way to his experiences as a boy on the farm, the speaker will assert that he, too, "was once a bare-foot boy," and that in the woods of Maine when he desired to find snow in June or July, he went to the forest, as did other boys. In the open country crops were approaching maturity at that time.

Generalizations based on observations in a limited area are dangerous, and it is a fact that, if one travels along the Sierras from south to north, he can find exemplified practically every condition of snow-melting and run-off, some of which conform to the conditions stated by Colonel Chittenden and others to the conditions which he declares never exist. Let him take a wider range of observation in the matter of snow-melting and consequent run-off, and out of his own mouth will he disprove his assertion.

The speaker will not discuss the obvious errors shown by Fig. 1. In view of the foregoing, it should be clear that, for the greater part of the United States, the legends on the two curves should be transposed.

From pages 254 to 256 the implication seems to be that the greater part of the snow in the forest is lodged on the branches of trees, and that the part which passes through to the ground is of a light and feathery nature, the whole presenting an admirable focus for quick melting by subsequent rains. It is stated that "of an 18-in. fall, perhaps 12 in. is on the trees and the rest spread evenly on the ground." The whole picture is deceptive. If the author will visit the forests of the Northwest, with which he appears to be most familiar, he will find, in some sections, two sets of trail marks on the trees, one close to the ground for summer guidance, and the other from 10 to 15 ft. above the ground for the guidance of the winter traveler, who is walking at approximately that height on the top of the snow. Of course, during any snow storm a large amount of snow will accumulate on the trees; but it is undeniable that the first sweeping wind which rushes through the forest, after the snow has fallen, will blow off the greater part thereof, and it will find lodgment on the ground. Therefore, the

Mr. Leighton.

fanciful presentation of a light and fleecy snow, two-thirds of which is held aloft for the greedy melting of the spring rains, finds no justification in actual experience. What proportion, for example, of a total snowfall could the trees sustain, when the layer on the ground is from 10 to 15 ft. deep?

The author's comparison of the run-off from Puta Creek and American River is unfortunate, for he has given a total mis-statement of relative rainfall and run-off on the two areas, as is shown unmistakably in Mr. Pinchot's discussion and diagram, Fig. 16.

In the author's discussion of practical effects, it will be of interest to consider the hypothesis that records of 200 years are necessary to establish the trend of run-off as affected by forest cover and deforestation. It has been demonstrated by the work of the Geological Survey that, in a period of 10 years, run-off conditions, in practically all parts of the country, are comprehended, from one extreme to the other. It may be that, here and there, an extreme low or an extreme high water may occur in one decade which is not reached in another; but this is of no consequence in summing up the tendencies of the river to floods and to low waters. These extreme conditions are mere sports, due to unusual occurrences, and it is as illogical to consider them as representative of general tendencies, as it would be to accept the physiological and anatomical freaks in a museum as representative of the human race. The comparison of run-off conditions in 10-year periods has been well set forth in an article* by John C. Hoyt, Assoc. M. Am. Soc. C. E. Therefore one need not despair because the records do not comprehend the 200 years which have been prescribed by certain engineers.

The claim that a 200-year record is necessary arises from the fact that the investigators are looking for freak conditions, in order to endeavor to substantiate certain hypotheses. If the details leading up to the floods and low waters be examined, the whole matter resolves itself into the task of ascertaining cause and effect. The real question to be solved is: Does a rainfall of a certain depth, at a certain season of the year, cause a greater flood since deforestation than it did formerly under well forested conditions? Now, the answer to this question can be ascertained from recent records. Cyclical changes, so-called, in precipitation do not enter into the question, because the whole record is reduced to a common basis, irrespective of cycles, but depending solely on actual depth of rainfall and comparative conditions of ground surface. The author, in presenting Table 1—extreme gauge records on various streams—merely reveals a fundamental misconception. It is not the contention of well-informed persons, as far as the speaker is aware, that deforestation produces higher floods. The real effect is to cause more frequent and more prolonged floods.

* *Engineering News*, April 23d, 1908.

Mr. Leighton.

Especially high floods are the direct result of excessive rainfall which continues after the ground has become saturated. In such a case the forest is merely an assurance that all available ground-storage capacity shall be used. Therefore, the presentation of highest and lowest gauge heights is gratuitous. No one who has given deep consideration to the matter expects them to be productive of any definite conclusion.

There is another curious error revealed by Table 1, namely, consideration is not given to the depth of rain that produced the high stages. This is an all-important element in the matter. There are rivers in the United States in which there has been a decided diminution in flood occurrence and flood frequency, and if these two items were taken alone the result would mislead. Examination of the rainfall records for these river basins shows that there has been a greater proportionate diminution in rainfall, and especially in flood-producing storms, than in actual floods. Therefore, when the two are compared, it is apparent that there is an actual increase in flood tendency in the river. Further elucidation of this will be taken up in connection with the Tennessee basin.

In a foot-note on page 263 the author has approached the crux of the matter in some observations concerning the Ohio and Connecticut Rivers. Had he realized the importance of these two cases, he would not have relegated them to a foot-note. In contradistinction to the facts there given, the author asserts that there has been no change in forest conditions on the drainage areas mentioned during the period of record. Fortunately, the speaker has been able to make an examination into the situation. Only a few days ago, he observed a large amount of timber-cutting taking place on the Monongahela drainage. Credible testimony further assures us that deforestation is still going on over this basin. This is verified by the report of the Bureau of Statistics, Department of Commerce and Labor, for 1907. Pennsylvania is the ninth State in the Union in timber production, the yield for 1906 being valued at nearly $30 000 000. According to the Forest Service, the bulk of this is cut in the central and western parts of the State, a large amount coming from the Allegheny basin.

Again, with reference to the Connecticut drainage area, it is true that small timber is growing up on abandoned farms and that the total forest area may be as great or even greater than it was twenty years ago; but it is new forest, without the accumulated mulch. It will not render the same service to ground storage as the primeval forest.

On the other hand, original timber-cutting is going on. One of the parties financially interested in Turners Falls Dam, in Massachusetts, recently assured the speaker that, for the past quarter of a century, from 50 000 000 to 80 000 000 ft. b. m. of timber had been allowed to pass over the crest thereof each year. This certainly does

Mr. Leighton, not appear like a cessation of timber-cutting. On the contrary, Turners Falls is well down on the river, and, if the observations of lumbermen be true, and if the statistics of the Forest Service be justified, this amount of timber does not represent the extent of actual deforestation. This quantity of timber, from 50 000 000 to 80 000 000 ft. b. m., represents an enormous and constant drain on the primeval forest on the Upper Connecticut. So much for the facts. The line of inquiry suggested in Colonel Chittenden's foot-note will now be developed.

The diagrams, Figs. 8 to 15, inclusive, have been prepared to show:

First, the record of rainfall in each place for the period of observation;

Second, the number of days in each year during which the gauge stood at or above a certain designated point which may be considered as the flood point. (The point chosen in these cases may or may not be the true flood point; but the fact is immaterial. The presentation of data in this way is, in its essential result, merely the cutting off of the top of the hydrograph and the summing up of the number of days. As long as the same point is used throughout the record on each river, the exact location thereof is of little consequence, because it is the relative flood duration, rather than an actual numerical record of total height, that is desired);

Third, the expression of the number of days in terms of precipitation. Each diagram is the expression of precipitation as a straight line, and the further expression of the number of days of flood in terms thereof. It will be observed that such a record obviates the necessity for a two-century record of observation, because it gives the actual results of a unit's precipitation.

The fourth diagram on each sheet is the expression of the total rainfall in each 10- or 5-year period, such periods being progressive. Thus, the first period may be 1880-89, inclusive, the second 1881-90, inclusive, and so on. Such an expression gives the concrete view of progressive flood tendencies. The wide annual variations in precipitation and the resultant run-off effects thereof, by this method of expression, are smoothed out and compensated, and afford a less involved idea of the actual trend of events. The fifth and sixth expressions are those of total days of flood and the relation of one to the other, all in progressive periods, as in the fourth expression. It will be appreciated that the last three are composed of the same original data as the first three, the only change being the method of assembling the facts. A mere glance will show that flood tendency on all these basins is increasing, and an examination of their history will prove that while, in some cases, a part of the change may be due to other factors, still the relative importance of those factors is insignificant in comparison

Mr. Leighton.

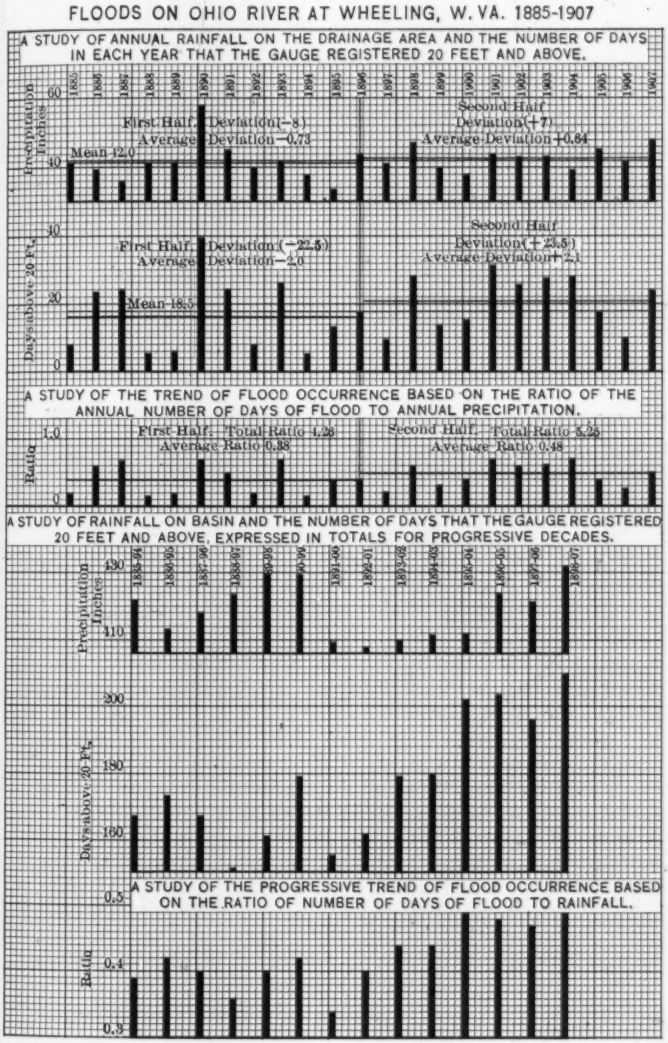


FIG. 8.

Mr. Leighton.

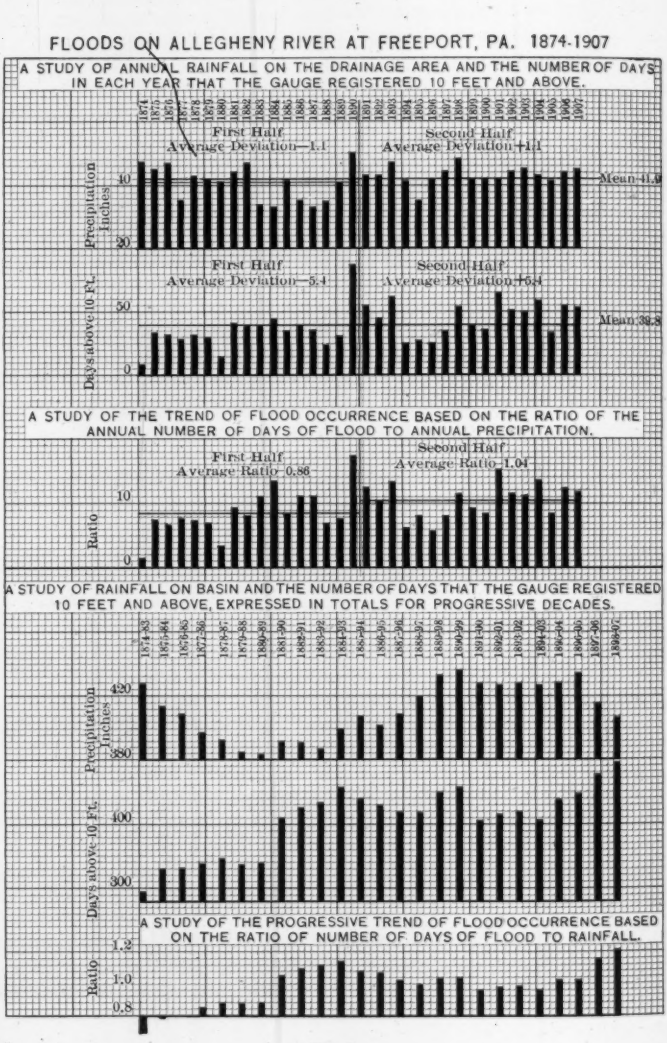


FIG. 9.

Mr. Leighton.

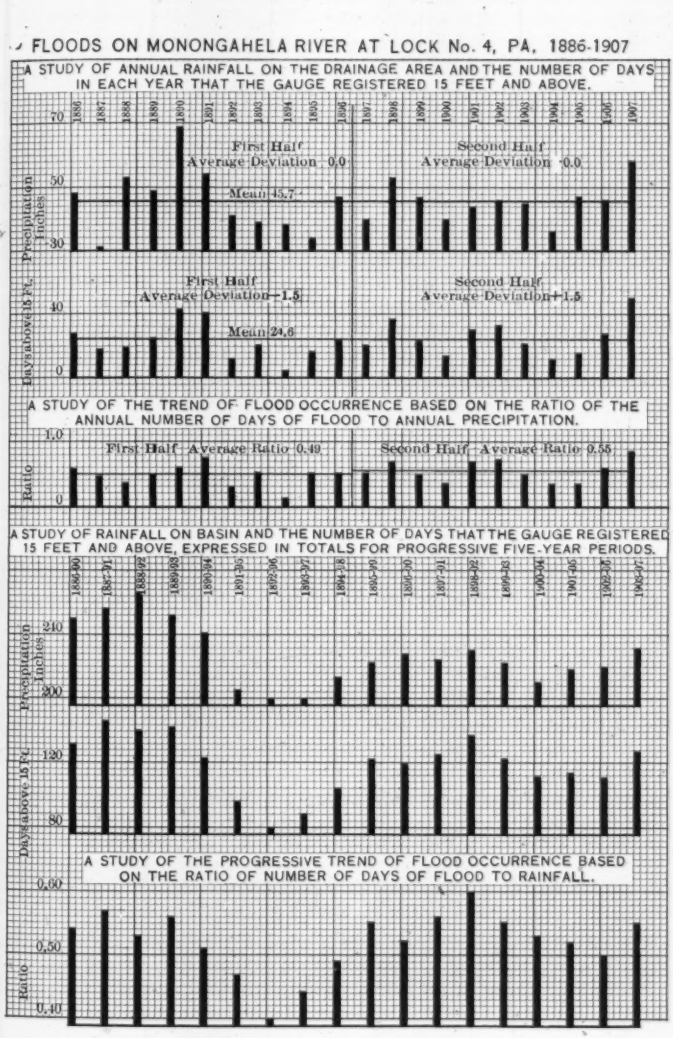


FIG. 10.

Mr. Leighton.

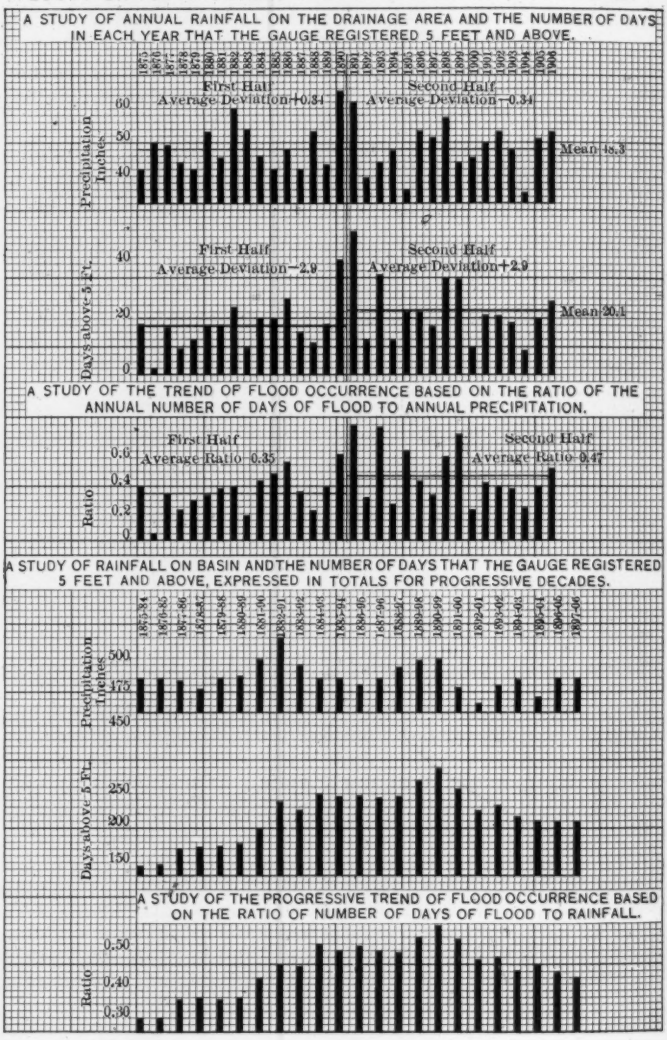


FIG. 11.

Mr. Leighton.

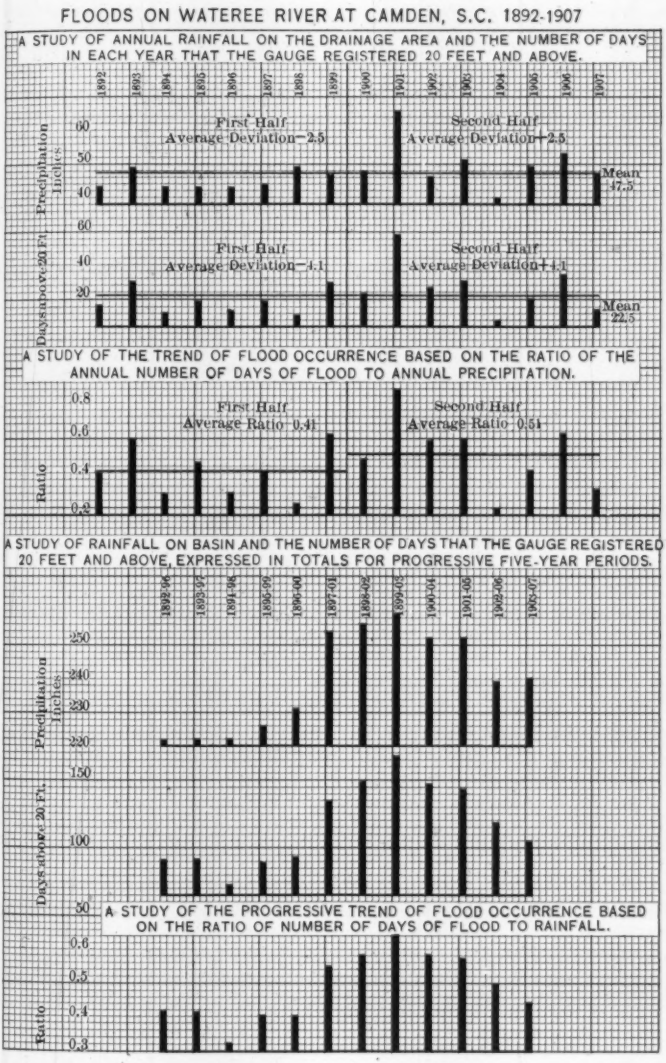


FIG. 12.

Mr. Leighton.

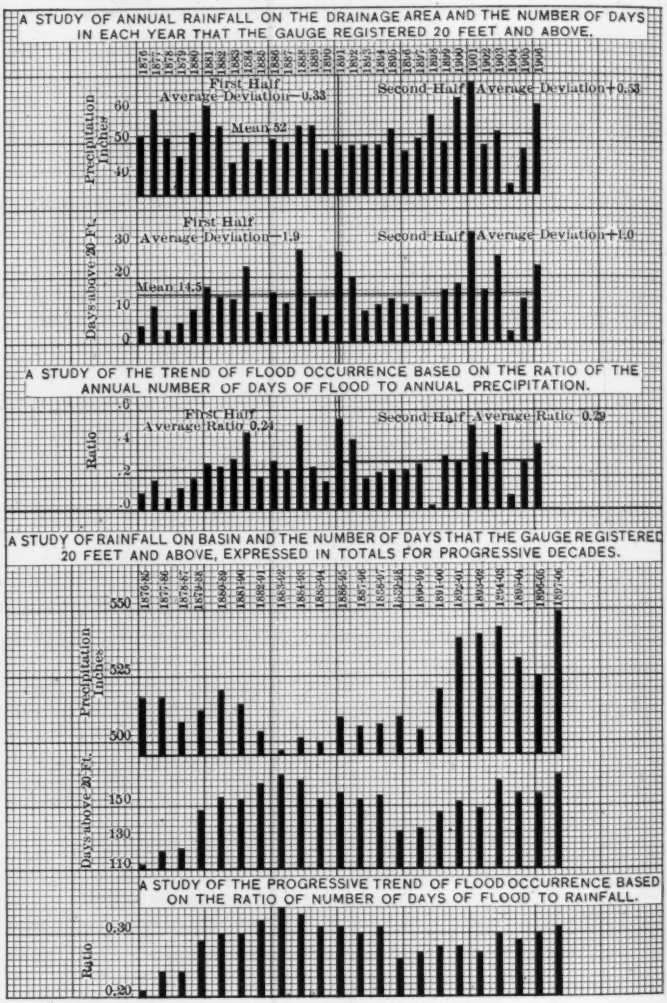


FIG. 13.

Mr. Leighton.

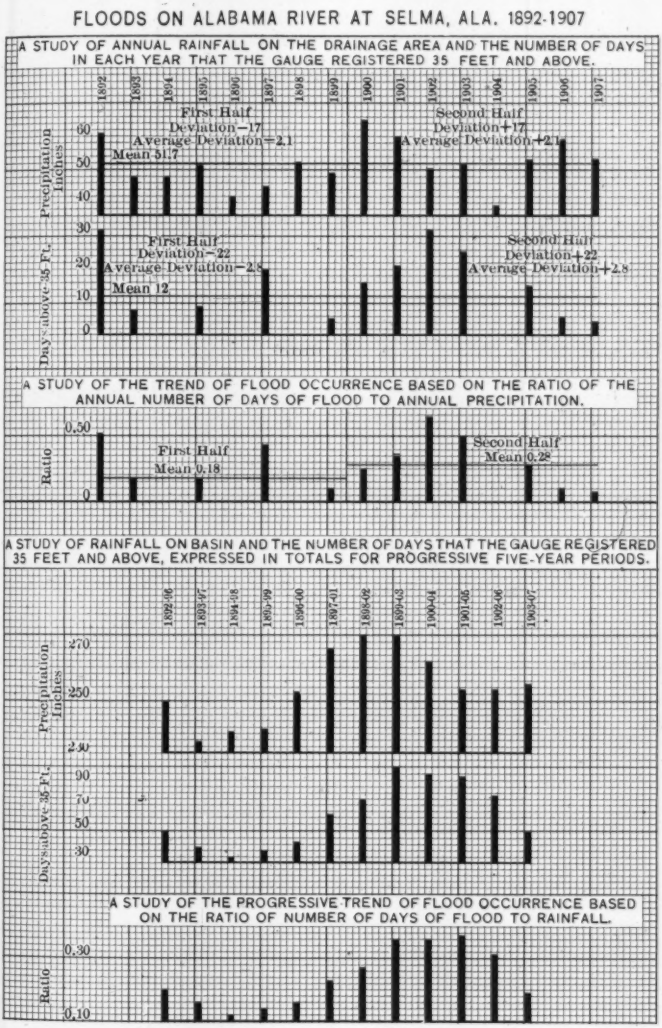


FIG. 14.

Mr. Leighton.

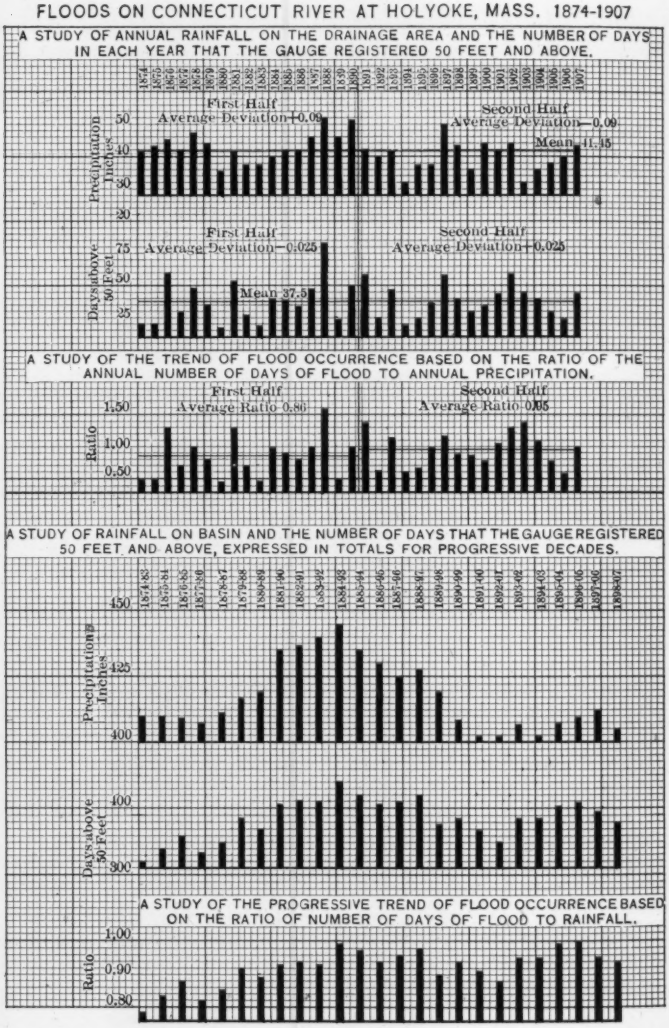


FIG. 15.

with the deforestation. In other words, the one great, predominating change in the character of the drainage areas during the period of record is deforestation. The history is clear, and the deductions are not subject to serious dispute. Mr. Leighton.

One of the interesting features brought out by these diagrams is the remarkable agreement in the progressive trend of the record on the Ohio at Wheeling, and those on the Allegheny at Freeport, the Monongahela at Lock No. 4, and the Youghiogheny at Confluence. The earlier lumbering operations of the Allegheny basin are shown clearly by the earlier initial increase in flood tendency. Examples like those presented by Figs. 8 to 15, inclusive, might be multiplied several times, and they would have been presented were it not for the excessive time and labor required in preparing the diagrams.

There is one point of objection to these diagrams which may reasonably be taken: It is that they draw comparison between annual precipitation and the number of days of flood. A better comparison would apply between the number and depth of flood-producing rains and the number of flood days. Such a comparison has been made on the Tennessee basin above Chattanooga. No other basins are here dealt with in this way, because of the enormous amount of labor involved.

In addition to proving beyond controversy the increase in floods due to deforestation, the record is of interest because it shows how futile and misleading is the attempt to derive conclusions from flood records without taking into account records of precipitation. Inspection of the Chattanooga flood record shows a decided decrease in the number and duration of floods during the period of record. If this were taken alone, it would controvert the forest-control idea. A comparison of the precipitation records on the drainage area, however, assures us that the rainfall has decreased, even to a greater relative extent than the floods. The final result is that the flood tendencies have increased.

The results for the Tennessee basin cover 24 years, from 1884 to 1907, inclusive. Although the records of gauge height extend farther back than the earlier date, the number of rainfall stations maintained on the basin previous thereto is not sufficient to render safe any conclusions with reference to precipitation. It is appreciated that a given depth of rainfall precipitated during the winter months will generally produce a greater run-off than the same depth would produce in August or September. Therefore, an effort has been made to eliminate this source of error. Summing up the flood-producing rains for the 24-year period, it is found that the total is 335, of which 313 occurred from December to May, inclusive, and the remaining 22 during the other portion of the year. It is apparent that the number of such rains from June to November is not sufficient to afford a basis

Mr. Leighton.

TABLE 13.—THE RELATION BETWEEN STORMS AND FLOODS IN THE TENNESSEE BASIN DURING THE PERIODS DECEMBER-MAY, INCLUSIVE, 1884-1895, AND 1896-1907.

Period.		Storms, in inches precipitated.															
		1-1.5		1.5-2		2-2.5		2.5-3		3-3.5		3.5-4		4-4.5		4.5-5	
		Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.
1884-1895		7	5	12	6	6	15	5	9	5	13	6	30	1	6	2	17
1896-1907		8	3	11	10	9	23	11	30	4	13	1	6	1	8	3	20

Period.		5-5.5		6-6.5		7-7.5		8-8.5	
		Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.	Storms.	Days of Flood.
1884-1895		2	18	..	..	2	28	1	17
1896-1907		..	..	1	11	..	..		

of comparison. Therefore, only the December to May floods will be considered. In making this comparison, the ideal condition would be to compare the rainfalls and floods during identical conditions of climate, but such a refinement is impossible. On the other hand, the multiplication of data afforded by the large number of flood-producing storms in the December-May period warrants the conclusion that the varying climatic conditions in this period are compensated, and the final conclusions which are drawn from the result must be worthy of confidence. Dividing the period covered by these 313 floods equally, two consecutive 12-year periods are afforded, which give a basis of comparison. The floods in the later period, resulting from a given depth of storm precipitation, are shown clearly to be more severe than in the earlier period. The method of presentation further makes it possible to compute the increase in flood tendency due to deforestation. In the Tennessee basin it is 18.75 per cent. Mr. Leighton.

If the number of flood days is divided by the number of storms, the result will be the number of days per storm. Applying this to each of the series in Table 13, the result given in Table 14 is reached.

TABLE 14.—DAYS OF FLOOD PER STORM, 1884-1895 AND 1896-1907.

Period.	Storms, in inches precipitated.							
	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5
1884–1895	0.7	0.5	2.5	1.8	2.6	5	6	8.1
1896–1907	0.4	0.9	2.6	2.7	3.2	6	8	6.7
Percentage of increase.	— 43	80	4	50	22	20	33	— 17

The algebraic sum of these percentages is 149.00 and the average is 18.75, which sums up the effect of deforestation on run-off from 1884 to 1907, inclusive.

The author devotes some space to a discussion of the effects of forests on rainfall, and concludes that there is little or none. For the purposes of the present discussion, the question is in no wise involved. The requirements are satisfied with the record of actual precipitation, be it decreasing or increasing. Colonel Chittenden, however, oversteps the bounds of conservatism when he asserts:

"Coincident with our recent high waters, which are attributed so largely to deforestation, there has been an increase in precipitation, where there should, apparently, have been a decrease."

Let the author examine the precipitation records over the basins of the Tennessee, Cumberland, Kentucky, Pemigewasset, and Catawba Rivers, and he will be convinced that his generalization, in these important instances at least, is quite the reverse of the truth.

Mr. Leighton. The author expresses a preference for floods over dry years, and he assures the reader that dry seasons are sure to follow floods.* The sequence is hardly obvious in the light of past experience. The present year, 1908, for example, has been one of the severest in our history, from the flood-damage standpoint, and yet the rivers have been extremely low a great part of the time. The Ohio has been visited by no great floods; yet the drought has been the worst in the last half century. On the other hand, the Ohio was visited by disastrous floods in January and March, 1907; yet, during the following summer, the river was not abnormally low. The author's generalizations are precarious.

The expressed preference of the author for floods over dry seasons suggests the query whether or not he has ever considered the extent of the country's flood damage. It is plain, from the statement quoted, that he has disregarded the worst element of loss, viz., the flood-water itself. A flood is essentially a waste of water which might be put to a useful purpose; but, apparently, he does not realize that floods, during 1908, have caused a physical damage of $260 000 000, and the end is not yet. Nor does this figure take account of the property depreciation resulting from flood menace, which would more than double the total.

There still remains much to be said, but the speaker will forbear discussion of Colonel Chittenden's statements concerning forest control of erosion, except to state that, if he will accompany the speaker on a journey of one week to portions of this country with which he is evidently now unfamiliar, he will willingly withdraw this section on erosion. His fundamental misconceptions concerning erosion may be explained by a little consideration of dynamic geology.

The speaker, at his solicitation, has received from Dr. W J McGee,† a comment upon certain features of Colonel Chittenden's paper, in which he remarks that Colonel Chittenden errs in that he assumes that there is no connection between rivers considered with respect to improvement and the sediment that they carry, and again when he holds that water is the object matter of engineering art and sediment the object matter of scientific farming. Such misconceptions explain the erroneous deductions respecting the Missouri River. Dr. McGee notes Colonel Chittenden's declaration in one sentence that the Lower Missouri takes its sediment from the Bad Lands and his equally emphatic utterance in another sentence that the sediment carried by the Missouri and other rivers is merely local freight. Dr. McGee then testifies that the Missouri is still a clear river after passing the Montana Bad Lands. He observes, further, that the Missouri normally gathers by bank caving nearly twice as much sediment in the State of Missouri alone as it pours into the Mississippi. "The only

* Page 269.

† Erosion Expert of the Bureau of Soils, United States Department of Agriculture.

sound basis for thought concerning streams," writes Dr. McGee, "is that of geology, in which running water is viewed as an agency, indeed as the most energetic and effective agency in earth making; and this property of water arises in the extraneous matter carried within it. Sediment-bearing water is fundamentally distinct in its behavior from clear water." Dr. McGee further contends that if these principles are borne in mind the conclusions at which Colonel Chittenden arrives would be impossible. Mr. Leighton.

With reference to the assertion that our rivers are not shoaling by reason of erosion, it may be remarked that, if the author will review the reports of the Chief of Engineers, U. S. Army, he will find ample evidence to the contrary. Of course, erosion does not mean uniform shoaling throughout the entire course of a river. It means rather additional bar formation. The schedule of dredging on the Ohio shows a fairly constant increase since 1875, and it is significant that, in the recent report on the 9-ft. canalization of this river, the Board of Engineers for Rivers and Harbors recommended that $1 000 000 per year be provided for dredging. While it is recognized that the need for this great sum arises from the cessation of bar cutting that would be occasioned by the erection of locks and dams, it indicates, nevertheless, that the United States Engineers have recognized that the débris problem is of far more consequence than Colonel Chittenden would have us infer.

The speaker will pass over the author's discussion of forest policies. Here again, his mistakes are fundamental, and his contentions contradictory; but a reply will undoubtedly be forthcoming from some persons better qualified than the speaker.

In reference to the section on artificial reservoirs, as the speaker has already replied to many of the objections,* he will merely refer to them.

It is evident that Colonel Chittenden recognizes fully the possibilities of the reservoir, and accepts the principle of conservation. Indeed, were one desirous of establishing this principle beyond all controversy, he would need but to take the report of the Board of Engineers on the Upper Mississippi Reservoirs,† of which Colonel Chittenden was a member, and, to demonstrate the absolute soundness of the reservoir principle, would have only to hold this report aloft and stand mute.

It is stated that Fig. 2 illustrates a contingency which nearly happened on the Upper Mississippi in the flood of 1905, namely, the operation of reservoirs to increase floods. The speaker is unable to concede the correctness of this deduction. Fig. 2 shows that the maximum flood height at Aitkin occurred from the 1st to the 15th

* *Engineering News*, November 5th, 1908, pp. 504–507.

† Pages 290 and 292.

Mr. Leighton. of July. On July 1st, the Aitkin gauge was more than 6 ft. above full-bank stage; yet the controlled flow from Pokegama was about 1 200 cu. ft. per sec., or less than one-half full-bank capacity. The Aitkin flood on July 1st was due, therefore, to the discharge from the uncontrolled area above Aitkin. Supposing, now, that the Pokegama area had been uncontrolled, the discharge on July 1st, according to Fig. 2, would have been 2 700 cu. ft. per sec. greater, which is equivalent to an increase of nearly 200% in excess of discharge over bank-full capacity at that time. The high point at Aitkin appears to have occurred on or about July 5th, at which time the reservoir discharge was approximately 2 200 cu. ft. per sec., or nearly 2 000 cu. ft. per sec. less than it would have been without the Pokegama control.

The sharp increase in the controlled Pokegama discharge which took place between July 5th and 31st, is accompanied by an equally sharp decrease in gauge height at Aitkin. When the gauge again began to increase on August 1st, the controlled discharge was 1 500 cu. ft. per sec. less than it would have been under natural flow, and, on or about August 10th, the date of the secondary flood crest at Aitkin, the natural flow would have still been teeming on, reaching its maximum some 10 days later; yet, in spite of the fact that the controlled flow continued to increase from that date until about September 12th, the flood at Aitkin showed practically continuous subsidence. Now, this secondary flood, culminating on or about August 10th, indicates a discharge of nearly 800 cu. ft. per sec. less than that culminating on July 5th; yet the natural flow at Pokegama would have been about 800 cu. ft. per sec. greater than is indicated at the height of the July flood.

The defect in Fig. 2 is that, while the author has introduced an hypothetical curve for the natural flow at Pokegama, he has not balanced it by a similar hypothetical gauge record for Aitkin, but has attempted to draw deductions by basing his computed natural-flow curve upon his controlled Aitkin gauge-height record. He observes that the sharp increase in controlled Pokegama discharge from August 1st to 10th, is accompanied by a sharp increase in gauge height at Aitkin for the same period, and, inasmuch as the controlled flow at Pokegama on August 10th is only about 350 cu. ft. per sec. less than it would have been under conditions of natural flow, he believes that the reservoirs nearly operated to increase the flood. Of course, this is a fallacy, because, under natural flow conditions at Pokegama, the Aitkin gauge record would have been entirely different.

The excess of computed natural flow over controlled flow at Pokegama between July 1st and August 10th (the crucial point at which the reservoirs seem to have become nearly inefficient) is approximately 5 230 000 000 cu. ft., and it is unquestionable that this would have changed the flood occurrences at Aitkin by carrying the highest gauge

point farther along in July, and affording thereafter a subsidence at a rate somewhat approximating the subsidence of the computed natural-flow curve. It is apparent, therefore, that, although the controlled flow at Pokegama is in one point actually greater than the maximum natural flow would have been, there is not the slightest reason for believing that this controlled flow came anywhere near adding to the severity of the flood which would have occurred without reservoir control. Mr. Leighton.

The author has based his conclusions on the relative natural and controlled flows at Pokegama, whereas the actual test of the matter lies in the record of the Aitkin gauge. His apparent tendency to regard the actual discharge from the reservoir as the important feature, rather than the actual effect on the river below, is further indicated by Fig. 3.

Fig. 3 certainly shows, as the author contends, that the controlled flow at Pokegama was not as uniform as the natural flow would have been; but is this not the whole purpose of the reservoir system? In the practical operation of reservoirs one does not seek to secure uniform discharge from those reservoirs, but rather to adapt the discharge so that, in connection with the uncontrolled discharge from lower tributaries, it may finally produce a condition of uniformity in the river many miles below, and not, indeed, in the river just below the reservoir outlet. It would have been eminently fair, in presenting Fig. 3, to have added thereto two more curves, one showing the discharge at Aitkin, Brainerd, Little Falls, or St. Cloud, as controlled by the upper reservoirs, and the other, a computation of what that flow would have been had the reservoirs not been installed. The reason reservoirs are installed may be, in some cases, that the flow at the point of installation is too uniform to combine satisfactorily with conditions in lower tributaries. Therefore, uniformity of reservoir-discharge flow is decidedly not the sole object. The fact that such discharge is not as uniform as the natural flow would have been is of no consequence in summing up the usefulness of the reservoir system.

The difficulties that Colonel Chittenden expresses, with reference to the effective operation of a system of reservoirs like that proposed by the speaker on the Ohio basin, apparently arise from the fact that he has not considered the great capacity of these reservoirs. Their effective capacity, in every case, is computed upon a total conservation of the water on 100% of a certain area. This is discussed at length in the paper. Of course, exceptional seasons would come when the floods would fill these reservoirs higher than at other seasons; but, if we take the actual records of such exceptional seasons, we shall find it very rare indeed when the flood run-off in any season, however prolonged, is as great as the total mean run-off of that area for an entire year. Therefore, before a reservoir, the capacity of which has been

Mr. Leighton. adjusted to hold the entire mean run-off, has been overtaxed, dry seasons would intervene, during which the reservoirs would be needed to supplement the low-water discharge. But, supposing this were not always true; admitting for purposes of argument that there would be times, at rare intervals, when the reservoirs were overtaxed and a flood would descend on the valley below, does this make the proposition valueless? Is there not virtue in a project that will render floods extremely infrequent, instead of extremely common, as they are at present? The speaker believes that the proposed reservoir system could be operated always to control floods, but he contends that, even if now and then a portion of a flood should get past the reservoir system, there would still be ample benefits accruing from that system. Colonel Chittenden surely will not contend that because benefits are not 100% it is not well to secure 90 or even 80 per cent.

The same observation holds good for the low-water conditions. A storage of 100% begets confidence, and properly so; but, supposing there would be times when the reservoirs would be "too empty" to afford full supplementary flow during dry seasons, would there not still be a large measure of benefit for water-power purposes in a partial flow, and would not the condition be infinitely better than that which prevails to-day? Let us not be petulant. If we cannot secure a whole loaf, let us take three-quarters or even a half, remembering that the half is sometimes the sole arbiter between a dead man and a live one.

The observation that the proposed reservoir system would not, in the case of the flood of 1907, have helped the situation at Cincinnati indicates that Colonel Chittenden has fallen into the same error that Major Newcomer did in assuming that it was expected that the Upper Ohio reservoirs were to control the situation all the way from Pittsburg to Cairo. If, as stated, the maximum at Cincinnati and that at Pittsburg occurred about the same time, it ought to be plain that the flood-waters which furnished the maximum at Cincinnati did not come from the Pittsburg district. They came from lower tributaries, and the proposed system of reservoirs covers these lower tributaries.*

The author's river hydraulics become somewhat involved when he undertakes to discuss flood-wave propagation. The effect of flood-wave prolongation that he describes would be favorable, rather than detrimental, to reservoir control. In fact, the whole paragraph presents a symmetrical contradiction, and the speaker will endeavor to analyze the conditions.

There is established, in the Ohio River, a certain flood regimen in which are comprehended all the flood phenomena, including progress of crest, prolongation of wave, etc. When, in his original report, the speaker discussed the effect of reservoirs, he did not start at Pittsburg with a certain crest and volume, and compute what the effect would

* Further discussion of this point may be found in *Engineering News*, November 5th, 1908, pp. 504–507.

be at Cincinnati and other points along the river. Had he done so, then, indeed, would it have been necessary to account for all the phenomena of flood transmission. Fortunately, observations at lower points rendered this unnecessary. The regimen has been observed; what happened at Wheeling, Cincinnati, etc., is known and also what contributed to the conditions there. Now, what is the effect of the reservoir system as proposed? It is not that of prolongation of flow; no attempt is made to flatten the wave by allowing the same amount of water to discharge in a longer space of time. The element of time remains unaffected, save that which results from change of head. The real effect is to cut out from the drainage area a certain portion which otherwise would contribute to the flood. A flood wave at Pittsburg would contain equivalently less water; and, knowing what actually happened there without flood storage, one can compute approximately what would take place as a result of the reduction. This reduction would not be the equivalent of the area cut off; it would be greater, because this area is steeper than the average for the whole, and, therefore, its flood wave is the more quickly transmitted to the lower valley, as demonstrated by Colonel Chittenden. The special point that he makes, by the way, is not involved in the discussion, for no one is contending that upland streams are subject to over-bank floods. In establishing storage reservoirs, efforts are made to protect the lowlands, not the uplands, and it is self-evident that they are most in need of protection from these upland streams, which are of so large a unit discharge capacity and so swift in flow that they do not inundate their own lands, but quickly deliver their floods into the lower rivers of relatively small capacity. Mr. Leighton.

Proceeding now with the matter of flood propagation, let it be assumed that the problem has these elements in it. Colonel Chittenden starts with a flood at Pittsburg increasing from 100 000 to 200 000 cu. ft. per sec. It is asserted that this would not produce a similar increase at Cincinnati. Very well, but is this not in our favor, and are we not on the safe side, as far as flood damage is concerned, if we assume that the increase will be as great in one case as in the other? The rule should work both ways. If an increase of 50% in the discharge at Pittsburg does not produce a similar increase at Cincinnati, should not a decrease of 50% at the one place effect a greater decrease at the other?

Carry the matter up past Pittsburg, even to the reservoirs. If, by manipulating the gates, 50% of the flood is conserved, a reduction equivalent to that assured by the author would take place when the crest had reached Pittsburg, and, in proceeding down the Ohio Valley, it will be reduced still further by the time it reaches Cincinnati. Why, then, would not the reservoirs have 125% of the predicted results, instead of 75%, as Colonel Chittenden suggests?

Mr. Leighton.

With reference to the matters of cost, local obstruction of highways, communication, safety of dams, and overflow damages, the speaker will refer to his article above referred to.* The speaker will accept Colonel Chittenden's estimate of cost, $500 000 000, and will still insist that the investment will be eminently wise. The author has made a distribution of expenditures covering the Mississippi and Ohio Rivers, including navigation and flood protection; but, with all this accomplished, still would we be wasting the flood-water which is so much needed; still would we have low water and foul streams, with unspeakable conditions on the Ohio, like those of the past summer and fall; still would we be obliged to provide for water-power, our sole hope as a source of energy in the future; still would we be wasting our precious and fast-disappearing supply of coal. Why is it that we refuse to take the long, broad, comprehensive view ahead, and provide manfully for all future contingencies and economic demands? Is the old, the narrow, the conventional road, the course of which traverses a circle, always to confine our steps?

The final point of error on the part of Colonel Chittenden is that of the speaker's alleged estimate of returns to the Government by reason of additional water-power made possible by reservoir construction. The fact that three good men have successively published comments thereon, under the assumption that the speaker has estimated a return of $20 per horse-power-year, leads him to believe that there must be some statement or turn of phrase in his report that warrants such an inference. He has been unable to find it, and refers those interested to his statement in *Engineering News* above cited. Throughout his whole consideration of water-power, the speaker has used $20 per horse-power-year merely as a factor to indicate approximately the value of the power, and not the Government rental.

One more word, and that with reference to the author's strictures concerning the speaker's "reversal of obligation." It is in testimony of Colonel Chittenden's progressive attitude that he makes this stricture. He asserts that the reservoir principle is accepted, and that the cost is the only remaining bone of contention. Would that this were so! The principle is still widely doubted, in testimony of which the author should review recent utterances and writings of some of his brother officers. The existence of suitable reservoir sites in the Ohio basin is not accepted universally, in testimony of which see same utterances and writings of same parties. The original report, presented by the speaker to the Inland Waterways Commission, was designed to defend the principle and to announce the existence of reservoir sites, and, finally, to make a plea for a worthy examination which would include this matter of cost as well as all other uncertain items.

* *Engineering News*, November 5th, 1908.

W. D. PICKETT, M. AM. SOC. C. E. (by letter).—Colonel Chitten- Mr. Pickett.
den's paper and the paper by the writer entitled "The Floods of the Mississippi Delta: Their Causes, and Suggestions as to Their Control,"* indicate to the casual reader a radical antagonism, apparently, as to the effect of the shade of forests on the melting of snow; also, as to the effect of forests in retarding the flow of rain or snow water on mountain or hill sides. It would seem that the first question is whether snow will melt faster (especially at elevations of 8 000 or 10 000 ft. above sea level) under the direct rays of the sun, or when protected by shade, such as pine forests afford.

The second question is whether rain or snow water will reach a stream when flowing over a comparatively smooth surface, such as cultivated fields, in less time than when flowing over a surface obstructed by the roots and trunks of forest trees and by the brush and other impedimenta common to all forests.

It would seem that there is but one answer to these two propositions, and that between two engineers, each with exceptionally good opportunities for observation of the themes of which they write, this antagonism must be more apparent than real, if their views are elaborated and explained.

The object of this discussion is to explain and particularize the writer's views on the subject. In the writer's paper the cause assigned for the disastrous floods of the Mississippi Delta was the merging, near the mouth of the Ohio, of the "Spring Rise" from that stream with the "June Rise" from the Missouri, and the passage of the combined flood toward the Gulf. It was also pointed out that the only means of preventing the coincidence of these floods at or near the mouth of the Ohio was by the construction of reservoirs of the requisite capacity, at the head-waters of the Missouri, to hold back the annual floods a sufficient length of time to allow the spring flood from the Ohio to pass down and out of reach, without peradventure, of the later "June Rise" from the Missouri.

It was suggested that Nature had already pointed out the most feasible and effective reservoirs, by the creation of those vast pine forests at the head-waters of the Missouri, and that these are vast storage reservoirs in which the accumulated snows of winter are preserved until gradually turned into water in summer. These forests are usually found in that portion of the Great Continental Divide between elevations of 7 700 and 9 200 ft. above sea level, usually designated the "Timber Belt." It was pointed out that within this timber belt there are vast areas of open land, which were formerly covered with pine forests, but which, from unknown causes (supposed to be from fire), had become denuded, thereby exposing the snow to the direct rays of the sun. The area of these open mountain plateaus

* *Proceedings*, Am. Soc. C. E., November, 1908, Vol. XXXIV.

Mr. Pickett. was estimated as about equal to that of the pine forests already existing on the timber belt.

It was also pointed out that, from the writer's 15 or 20 years' observations, the snow in these open areas usually melted and flowed to the valleys during May or the first days of June, a month or six weeks earlier than the snows stored up in the forest reservoirs. These remarks are confined to localities within the timber belt.

The writer also stated his belief that the early melting of the snows on these open plateaus around the higher portion of the entire Missouri River water-shed is the principal cause of the "June Rise" in that stream.

Evidently these plateaus were once clothed with forests, and Nature teaches that these areas, with few exceptions, can be re-clothed with forests by using the means that Science prescribes. When that is accomplished, the winter's snows will melt so gradually during the early summer as to prevent those spasmodic floods of the local streams which, when finally combined in the main stream, become known at its mouth as the "June Rise."

By the remedies advocated this flood will be held back at least a month, and considerably modified in intensity and volume.

It was also pointed out that one factor in retarding the melting of snow during the first warm months is the comparatively low temperature of the air at such elevations as the timber belt; that after the snow commences melting in the forests there are few nights in June, July, or August when the temperature is not low enough to form a snow crust firm enough to bear the weight of a man or even a horse. The actual melting of the snow occurs during about one-quarter of the 24 hours. The warm currents of air circulating through the timber cause the surface of the snow to soften, and hence the crusting at night.

In open areas, on account of the radiation of the heat given out during the day, the temperature is not as low as in the timber, the crusting of the snow is not as effectual, and its melting goes on during at least three-fourths of the 24 hours, and in the direct rays of the sun is much more rapid, and at times continues during the entire night.

Another consideration affects the melting of snow in the timber belt: The accumulated snows of winter represent what has fallen in different layers or storms from September to May. With the rain or melted snow that falls in May, June, and July, the water used during the irrigating season represents, as before explained, the entire precipitation, practically, for the year ending September 1st. The layers of snow that fall in December, January, February, and March are deposited, and, before the subsequent layer falls, are subjected to temperatures ranging from 20 to 40° below zero, depending on the winter conditions.

Mr. Pickett.

These are the temperatures recorded at an elevation of 6 500 ft.; at the altitude of the timber belt, they must have been much lower. with the gradual settling and compacting of the snow during the winter these temperatures must have been stored up, to a considerable extent, under the protection of the forests.

In the open areas, however, the snows, after successive layers have been deposited by winter storms, are exposed more or less to the direct rays of the sun (for in the winter clear skies are the rule in the timber belt), and the temperature of each layer of snow must have been higher than when first deposited. From these causes alone the snow in the open areas would melt sooner.

The foregoing gives the writer's views and the reasons for the much more rapid snow-melting in the open areas of the high mountain plateaus, the re-clothing of which with forests is considered so important for irrigation as well as for the prevention of floods in the Mississippi.

These views have been impressed upon the writer by a residence of 15 or 20 years in the valley of the Grey Bull, during which cattle interests compelled him to study climatic conditions. Previous to 1883 seven or eight months of each year (for seven years) were spent on the head-waters of the rivers radiating from the Yellowstone National Park. During these explorations the writer obtained an intimate knowledge of the topography of about 100 miles in length of the Continental Divide and of the extensive groups of mountains on each side. Within four miles to the south of his ranch there was an elevation of more than 8 000 ft. on the northern border of an extensive mountain plateau containing one peak of 13 300 ft. elevation, and others of 10 000 and 11 000 ft. elevation. To the north, within 10 miles, there was a similar plateau of less extent, each being a good summer range for cattle. The writer and a neighbor secured, and for years utilized, the mountain plateaus to the south as a cattle range. The importance of placing herds of cattle on this range at as early a date as possible, in order to reserve the "fenced-in" pastures for winter range, necessitated many trips to the top of the mountain to determine how much of the plateau was free from snow and had sufficient new grass to sustain stock. In these trips the marked difference as to snow-melting in the pine forests and in the open areas was forced on the writer's attention.

In several seasons there was sufficient grass in the open areas to permit moving the cattle to the mountain as early as June 10th; sometimes, in backward seasons, this was not done until toward July 1st.

In carefully reading Colonel Chittenden's views as to snow-melting, the points wherein he differs from the writer may admit of explanation. While conceding that snow melts faster in open areas, the author claims that when the snow in forests commences melting it

Mr. Pickett. goes faster than if in open areas. In the timber belt this does not hold good in June, July, or the first weeks of August. The snow in the forest that softens on top, or perhaps partly melts, is crusted over or frozen at night, so that the melting or softening is not resumed until noon or later the next day.

His view is correct when referring to the valleys of 5 000 or 6 000 ft. elevation, and there the drifts he mentions go very rapidly. These drifts commence to melt in April and disappear very rapidly during the wet snows and rains not infrequent in April and May. The writer thinks he has an exaggerated impression of the value of the small gulches or depressions in the plains below the mountains. The writer's observation is that sage brush (in evidence everywhere except on the high ridges which have been denuded of soil by high winds) effectually prevents the drifting of the snow when of ordinary density.

Twice (1881 and 1882) the writer crossed the Yellowstone about May 1st at Benson's Landing and passed around the foot-hills bordering the Yellowstone Valley on the south, by the Upper Indian Lodge Pole trail, to Clark's Fork, a distance of 60 or 75 miles. Though crossing on each trip numerous small gulches, that earlier were full of snow, there was no snow anywhere, but the streams of any size were high from the melted snows. The writer differs with Colonel Chittenden, as to the efficacy of snowdrifts in preserving snow at any altitude when subject to the direct rays of the sun. Pine forests, even at high altitudes, are more efficacious.

Figs. 1 and 2, Plate XXXVII, confirm the writer's ideas in reference to snow. The photograph of the forest shown on Plate XXXIX was evidently taken just after a snowstorm. A wind of greater or less power always follows such storms, and soon deposits the snow on the ground. The temperature of the air is usually too low to permit the snow to melt, even should the wind fail to dislodge it. If the wind blows parallel to the lay of the forest during a snowstorm, the forest will retain only its share of the snow; but in the high mountains it frequently happens that a forest is on the windward slope, and in that case the wind will drift the snow under the limbs of the trees and form large drifts well up into the timber. At the end of winter, such drifts are sometimes 6 ft. deep. In one locality the wind has such velocity in passing over a mountain, above the timber line, that snow is taken up and drifted a mile or more and deposited in forests at lower altitudes. This occurs every winter.

The following is an index of the effects of the sun's direct rays on snowdrifts in the plains below the mountains: On April 1st, 1893, the writer was delayed by the washing away of a bridge and trestle on Heart River near Mandan on the Northern Pacific Railroad. In passing over the reconstructed bridge the cultivated field in the river

bottom was partially covered with blocks of ice from 2 to 3 ft. thick, which had been brought down on the flooded river. This stream had its rise about 100 miles westward in the famous "Bad Lands," the deep gorges in which are conducive to the formation of extensive snowdrifts. In this instance the sun's rays had quickly done their work. The Missouri River at Bismarck had been free of ice for some time previous to that date. Mr. Pickett.

It seems to the writer that there can be only one opinion in regard to the effect of forests in retarding the flow of rain to the streams below, thereby preventing sudden floods. Applying the illustration to the water-shed of the Ohio, suppose there is on a hillside a forest of average density, with all its impedimenta of roots and trunks of trees, underbrush, old logs, dead leaves, etc. On another part of the same hillside are cultivated fields, each portion extending to the stream at the foot of the hill. Suppose now a steady rain of average flow is falling on these two areas. Can there be any doubt which section of that stream will first receive the water, that flowing over the cultivated field, or that flowing through the forests?

Leaving out of the question the obstructions offered by the roots and stumps, the increased friction of the water in running over the leaves and other smaller obstacles would decide the question. The parallel between the cleared fields and the forests is drawn because the disappearance of the timber is usually followed by the cleared fields. This occurs especially in those portions of the Ohio River water-shed in Ohio, Indiana, and Illinois. The destructive floods usually occur before the land is plowed for the coming crops.

Omitting all reasoning, these facts stare us in the face each spring; the much earlier floods from the Monongahela and Allegheny Rivers at Pittsburg; the greater volume and intensity of the floods; and the destruction of millions of dollars' worth of property in and around that city, and the devastation as far as the mouth of the Ohio. This did not occur fifty or sixty years ago, before this water-shed was denuded of its forests.

Civil engineers and planters state that below Memphis they watch with greater dread the floods from the Tennessee and Cumberland than those from the main stream, because the floods from those streams come earlier and with greater intensity and volume than was the case forty or fifty years ago.

The importance attached by the writer to reforesting the areas of the high mountain plateaus at the head of the Missouri River water-shed tempts him to recount the other benefits to the nation, besides those mentioned in his paper "The Floods of the Mississippi River Delta."

There are no records as to the extent of the forests and the adjoining open areas in the timber belt, but the writer feels confident that

Mr. Pickett. the areas of open land are as great as those which are forested, and, with few exceptions, these areas can be reforested.

There is a great length of the Continental Divide whose summits are not above the timber line, and are not as well adapted for the storage of snow as the mountain spurs making out from the main range and forming dividing ranges between the numerous streams having their origin in the main divide. These spurs are almost invariably high, and their numerous gulches are suitable for the storage of snow. That part of this divide between the heads of the Jefferson and Wind Rivers, with its mountain spurs branching eastward, is an example. These mountain ranges separate the West Gallatin, the Yellowstone, the Clark's Fork of the latter stream, and the North and South Forks of the Stinking Water and Wind Rivers. There are many portions of these subsidiary mountain ranges above the timber line with their summits topped off by peaks from 10 000 to 13 300 ft. high, such as Emigrant Peak, Bear Tooth, Pilot, Index, Franks Peaks, and the Washakie Needle, a mass of mountains about 100 miles in length and opposite the Yellowstone Lake, extending about 80 miles eastward. The valleys between these streams are narrow, sometimes partaking of the nature of cañons, with the dividing ranges on each side from 3 000 to 4 000 ft., above the valleys. These mountains have been explored by the writer and are probably more suitably fashioned for the storage of the winter's snows than any similar groups along the Continental Divide, but there are many others of somewhat less merit. There are also several groups of mountains, detached from the main range, that store up a great deal of snow. The Big Horn Range, about 100 miles in length, crowned with Cloud Peak, more than 11 000 ft. high, is the most extensive. North of the Missouri are the Bear Paw and Little Rocky groups, and these, though not of great elevation, are well adapted for the storage of snow.

The benefits to be derived from reforesting portions of the timber belt are: First, its importance for the irrigation of the arid belt contiguous to the tributaries of the Missouri. Secondly, its benefits, as a factor, in keeping apart the annual spring floods of the Ohio and the June rise from the Missouri. In his paper, previously quoted, the writer gives an estimate of the annual yield, in dollars and cents, of the land which will be reclaimed by the prevention of such floods. The data on which this estimate is based are given, so that any one can correct it according to his views. The estimate totals $376 200 annually. Thirdly, its favorable effects in controlling the floods of the Mississippi, by enabling the Mississippi River Commission to confine the stream to a fixed channel, thereby making safe the levees already constructed. If the writer's views and the reasoning sustaining them are correct, it is evident that one dollar spent in reforesting at its head-waters will save two or more dollars in the lower

part of this great river. Fourthly, its directly beneficial effect in the construction of that grand work "The Lakes to Gulf Waterway," a work of such national importance that the public already appears to have decided that it shall be constructed. Mr. Pickett.

Once confine the channel of this mighty river to fixed bounds, by such works as the River Commission has devised, and the solution of the problem would seem to be easy. The writer believes that there has always been a navigable depth of 5 ft. over the bars below Cairo. It is understood that by certain works to confine the channel, and by vigorous dredging, the Mississippi River Commission will be enabled to increase this depth to 10 ft. It would seem that by using all the appliances of modern engineering, and by forcing the river to assist in scouring out its channel, the additional cost of increasing the depth to 14 or 16 ft. would be inconsiderable when compared with the immense benefit to be derived by the commerce of the nation.

The essential part of the problem is the prevention of the merging of the spring floods of the Ohio with the June rise of the Missouri. That being accomplished, the third and fourth problems are easily solved, as far as engineering questions are involved.

As to the benefits from irrigation to be derived by the arid belt by this reforesting, the writer, from personal knowledge of the lands to be reclaimed, is confident that every gallon of water that may go to waste during the irrigating season could be used beneficially in the various parts of the belt.

The financial benefit to the nation, together with increased population and numerous other advantages, will make it certain that within a reasonable time every acre of this part of the arid belt, susceptible of crops, below an elevation of 6 500 ft., will be brought under cultivation.

According to a report of Elwood Mead, M. Am. Soc. C. E., in regard to irrigating works in the valley of the Po, in Northern Italy, that kingdom has expended millions of dollars in the construction of immense dams, reservoirs, and ditches for irrigation. The annual rainfall of that valley is about 43 in., or slightly more than that in the valleys of the Ohio and the Mississippi. When a nation like Italy can afford to expend millions on a part of that kingdom in which the rainfall is greater than in the States east of the Missouri, this great and wealthy nation will certainly, within a seasonable time, reclaim this extensive arid belt which, 60 or 70 years ago, was called "The Great American Desert" and was believed by some statesmen to be the western boundary of the country, as fixed by Nature.

In October, 1908, when in Montana and Northern Wyoming, the writer investigated the value of the lands in the arid belt when brought under the influence of irrigation and when there was a ready sale for the products of the soil. In Billings, Montana, in connection by rail

Mr. Pickett. with Northern Wyoming, a sugar beet factory, with all modern improvements, has recently been finished at a cost of $1 000 000. The superintendent stated that the factory was in operation and had just commenced receiving the present season's crop of sugar beets. He also stated that his company was paying from $4.50 to $5 per ton for the beets delivered at the nearest railway station, the price being regulated by the haul. He also stated that 15 tons per acre was about the average yield and that the cost per acre to ranchmen was about $30, making a profit of from $37.50 to $45 per acre to the ranchmen.

As the yield and profit per acre appeared to be very liberal, the writer obtained information from ranchmen and others who corroborated the figures given above; and the writer is informed that the best lands in Missouri, Iowa, Illinois, Indiana, Ohio, Kentucky, or Tennessee cannot make as good an exhibit.

There is every prospect that there will always be a good price for the sugar beet. The United States is now importing from 2 500 000 to 3 000 000 tons of sugar annually. The railway system of the West is gradually extending, so that in a few years every agricultural neighborhood will be reached.

All land under irrigation in Wyoming or Montana below an elevation of 6 500 ft. will bring forth a large yield of the beet. With the extension of the railway system, sugar beet factories will follow as soon as the length of haul becomes excessive, and it is certain that the railways will encourage the industry by proper rates, for they will have the advantage of handling the product twice.

The yield per acre mentioned above is not excessive. Without special pains, ordinary potatoes have been raised at the rate of 16 tons per acre, and this yield is not uncommon. A few years ago an agricultural paper offered a prize for the largest yield of ordinary potatoes; the prize was won by a ranchman of Sheridan County, Wyoming, with 940 bushels or 28 tons per acre. An experienced cattleman, instead of selling the sugar beet, considered it more profitable to feed them to his beef cattle.

These same lands will produce from 1 ton per acre at altitudes of 6 000 ft. to 5 tons at lower altitudes where three cuttings can be had during the season. Alfalfa brings from $5 to $8 per ton.

These statistics are authentic, and are repeated to indicate that the Government can make no mistake in expending liberally for storing up all the surplus water from the Missouri River water-shed that goes to waste during the irrigating season.

Mr. McMath. ROBERT E. MCMATH, M. AM. SOC. C. E. (by letter).—The author, by the title of his paper, has invited his readers to make an excursion into a boundless forest, in which many trails lead in many directions. He, in a measure, sets out to open and improve one trail, and very wisely suggests that members of the Society give "The results of their

observation and experience touching the important and vital features of one of the chief living questions of the day." Mr. McMath.

The writer feels disposed to protest mildly against the limiting clause of the title, "Reference to navigable rivers," because he knows no definition for navigable rivers, nor where to draw the line between the flotation of a chip and the largest ship. In the conservation and utilization of stream flow, as one of Nature's beneficencies, navigation comes last, but is not chief.

In discussing the paper, the writer would amend the title to read, "Reservoirs and forests in their relation to stream flow." Nature has determined the question of precedence by the fact that reservoirs are one of the controlling elements of stream flow, and has located reservoirs at every step from the hilltop to the ocean, and supplies water to fill the entire system from the great reservoir, whose importance in the administrative economy justifies the fact that three-quarters of the earth's surface is ocean. Incidentally, the oceans are useful for navigation, and the same is true, to greater or less degree, of the rivers emptying into them. The chief end of rivers is not navigation, but the conveyance of waters from higher to lower levels.

Nature has provided a goodly number of possible sites for artificial reservoirs to supplement the natural sites. The engineer who belittles reservoirs, their uses and possibilities, has not grasped the fundamental principle of river engineering.

In the final analysis it will be found that the possibility of reservoir extension is the measure of the success that may be hoped for in the way of a permanently improved Lower Mississippi, and a permanently protected delta, from the Ohio to the Gulf. This is a large assertion, but the proof is at hand.

Water at a high level represents potential energy, mass into head, $Q \times H$. In the passage of water from mountain top to ocean this potential energy must be expended in work.

If we assume the average volume of the Mississippi below the Ohio to be 500 000 cu. ft. per sec., and the elevation at that point to be 250 ft., there is a potency of about 20 000 000 h. p. to be expended in work each minute along some 800 miles of river.

If men load the stream with 100 000 tons of freight and let it float with the current, the load increases the mass, but the head is still H. The potency is $(Q + q)\ H$.

If Nature loads the stream with mud, silt, sand, and gravel to an aggregate of q_1, the capacity for work is represented by $F\ (Q + q_1)\ \frac{H}{l}$, l being distance.

As a matter of fact, Nature does not give a through bill of lading for the freight it commits to the river, but the load is dropped at way stations, as bars and accretions, and is replaced, in a measure, by scour

Mr. McMath. and erosion at other places. The interruptions of silt movement congest and obstruct the main line.

The conclusion is unavoidable, the potential energy of the river must be expended in internal work, attrition of moving gravel and sand, friction, boils, eddies, etc., in the stream, and in scour of the bottom and erosion of banks.

This view of river dynamics gives a clue to the difficulties attending attempts to improve great rivers by fixation of channel and banks. The old tradition of the housewife who fought the North Sea with her mop is not far from a parallel case.

The improvement problem may be fairly stated to be, How to give the potential energy, which Man cannot materially increase or diminish, something more to do than destructive work. We know that floods destroy, but we do not fully know and appreciate the fact that the work done at low stages is largely reparative. Reparative work is the readjusting and removing of high-stage, or flood, deposits so as to restore the efficiency of the river bed which is always impaired by flood waves. Assuming that such reparation is the fact, the practical solution of the improvement problem is to subtract from the flood and add to the low-stage energies. This brings reservoirs to the front, for they effect this exchange, and nothing else is known that will. The argument that they will not prevent all floods is not worthy of attention. The question is, how much can they be made to do?

From 1880 to 1883 the writer was employed by the then newly created Mississippi River Commission to make a special study of reservoirs, their possibilities, and their relations to river physics. He progressed far enough to realize that reservoirs were the natural and logical remedy for many physical ills, capable of ameliorating, if not curing.

He became convinced that the dynamic view of river physics, outlined above, was true beyond controversy, and that the first practical lesson was the futility of fighting against natural law when it is possible to work in harmony with it, by extending and especially by perpetuating Nature's reservoir system. Levees, revetments, and dikes, while locally useful and temporarily effective, should have a subordinate place.

It was then argued that concentration of flood waters between levees would "lower the Mississippi in its bed" and "set Cairo on a hill." When this idea gained official ascendency, the writer resigned his position and turned to another line of professional work.

Twenty-five years have passed, levees have been built and maintained along the whole delta course of the river; and millions have been spent. Has the river bed been lowered? Has Cairo, relatively to high waters, been elevated? Has any stretch of river of considerable length yielded to control and been permanently improved? The writer appeals to the records.

Mr. McMath.

The reservoirs already constructed and being operated at the headwaters of the Mississippi afford a very useful object lesson, if studied and the lesson applied intelligently. So far as the writer knows no such study and application have been made.*

The formal perfunctory Annual Reports to the Chief of Engineers drop a fact here and there, but are chary of giving interpretations. The following explicit statement is made in the Report for 1905, Vol. VI, page 1675:

"Without the reservoirs the discharge of the river at St. Paul is liable to fall to 1 700 cubic feet per second, as it has in the past, while with them the discharge can be readily held throughout the navigation season at or above 6 000 cubic feet per second."

That is, the present reservoirs are entitled to credit for a contribution of 4 300 cu. ft. per sec. to the Mississippi from below St. Paul to the Gulf of Mexico. For it must be borne in mind that a contribution to maintain a flow is subject to loss from absorption or evaporation only in the proportion that the augment increases the surface, which is very small. If delivery of the augment is delayed, and it be expected to fill a depleted bed, the losses by absorption and evaporation will easily consume the augment.

For this reason, the writer credits the reservoirs with the full amount of their contribution from St. Paul to the Gulf. A further contribution from the Great Lakes Reservoirs, *via* the Chicago Drainage Canal, is added to the Middle Mississippi at Grafton. The minimum discharge at St. Louis has been said to be about 40 000 cu. ft. per sec. A 10% increment from St. Paul and 20% more from Chicago is a material increase, and certainly assists in the formation and maintenance of the low-stage channel; but, from the writer's point of view, a more important result is the general condition of the river bed due to low-stage scour. Nothing will be said about bank erosions because they are not perceptibly affected by contributions.

Suppose this prepared condition, which ordinarily will last and progress during the winter months, is followed by a heavily silt-laden flood from the Missouri River. The water flood-wave will outrun the silt load which drops on and elevates bars; not only is the low-water channel obliterated, but the elevated bars are obstructions left by the flood-wave to impede the flow of subsequent flood-waves, which, to pass equal volumes, must rise higher on the gauge. In other words, flood-waves impair the efficiency of the regular river bed. Here lies the weakness of levees as a protection against extreme floods. There is not only no way of arriving at the volume that may come as a result of combinations of discharge from numerous tributaries, but in case of a

* The author in a foot-note refers to a report of a Board as containing "exhaustive data upon the system and its operation"; the writer has not seen the report.

Mr. McMath. succession of flood-waves, as the season advances, it is impossible to foresee what height on the gauge may be reached by a known volume.

When the Government undertakes to construct and maintain a levee system covering a long extent of river, the fact is accepted as a guaranty that complete protection will be furnished, and that the protected areas will invite occupancy and cultivation. If the levees are overtopped by unforeseen combinations of floods or are extensively breached by any of several forms of attack, the dire disaster to life and property will be greater as the levees are higher and as the sense of Government assurance of security is stronger.

The author has favored us with quite a long list of lions which may lie in wait in a reservoir system. The writer merely uncovers the existence of very savage lions along the levees' track as well. The moral is, use levees, reservoirs, and other methods of improvement within their appropriate limits and for proper purposes.

The appropriate limits and purposes of reservoirs depend upon conditions which vary with latitude, climate, topography, elevation, seasons of excess and deficiency of precipitation, the use made of impounded waters, the unreasonableness of men, and, the writer deems it necessary to add, to administrative action under defective legislation or want of legislation.

The latitude and climatic conditions of the Upper Mississippi differ radically from those of the Ohio Valley. The topography conditions of flat and hilly gathering grounds, season, and rate and quantity of precipitation are also very unlike. If there should be an Ohio system of reservoirs, there is little doubt but the leading or primary use would be for power, and so the executive in charge of operation, and there must be a supervising executive, may be relieved from the embarrassment of the Upper Mississippi executive, who tries to satisfy seven different and often conflicting interests (town water supply and irrigation might have added two more) without authority to decide which is entitled to preference or precedence.*

The shadow of the author's official experience in this connection is noticeable in the later pages of the paper. The whole story could not be told by an officer of Engineers, because it might be construed as criticism of "Official Superiors." A civilian is at liberty to say that the fault lies, with many others, at the door of The Congress.

To sum up the reservoir part of the writer's discussion:

1. Artificial reservoirs do have and will have a considerable moderating influence on floods, but that influence cannot control extreme cases; extremes, however, are exceptions.

2. Artificial reservoirs have many beneficial uses and, in comparison, few drawbacks.

3. Whether a possible reservoir site is or is not available, is a local

*Report, Chief of Engineers, U. S. A., 1905, Vol. VI, p. 1676.

question to be determined by an algebraic sum of "plus" and "minus" quantities, in which time is a variable factor. What was once easy is not difficult; what is now difficult will be more difficult later. Mr. McMath.

4. Passing from the Ohio and Upper Mississippi water-sheds, it is a reasonable expectation that the floods from the Upper Missouri, Yellowstone, Platte, Kaw, Arkansas, Cimarron, Cottonwood, North and South Canadian, and Red Rivers will sooner or later be held in reserve for the benefit of the arid and semi-arid regions of the Middle West. The aggregate of flood decrease, not so much as to height as duration, is tremendous. This, in the writer's opinion, is the chief hope for the Lower Mississippi for flood control, navigation, and security.

5. A river from source to mouth is an indivisible unit, though it has many branches and serves many uses.

The author's treatment of the influence of forests on stream flow is weakened by his omission of the very great and almost universally present fact of ground storage.

"The inclined-plane surface, practically impervious to water, with a layer of sand covering some small portion of it" with a uniform spray of water applied to the entire surface, has but little similarity to natural conditions.

Some years ago the writer visited the head-waters of the Meramec River, Missouri. A heavy fall of wet snow, about 9 in. deep, had covered the country with practical uniformity. After two days of bright sun and warm wind the snow was all melted, and the streams were running full.

The territory visited was near the junction of three streams, the drainage areas of which may be roughly estimated as being in the proportion of 1:3:4, with an aggregate area of about 2 500 sq. miles.

The smallest area has largely a clay subsoil of considerable depth, which is about as near an approach to an impervious surface as Nature makes; the underlying rock is sand and limestone. The slopes are moderately steep, largely cleared, and under cultivation. Conditions are favorable to active soil wash. The outlet stream is extremely turbid, the water being a dull brick-red in color, and the volume may be estimated at 150 000 000 gal. per 24 hours. Topographically, this stream should be the outlet for the second area as well as the first. It is known as the "Dry Fork of the Meramec," and is well named, for normally it is dry. The first area has no springs fed by stored water, but, as the area bears crops, a part of the precipitation, say 15%, must be absorbed.

The middle area is largely a sandstone formation with a porous top soil. The valley has a stream bed for emergencies, but it is normally dry; the stream bed practically ends at a cavern in the hill-side. There is plenty of evidence in the shape of drift that water

Mr. McMath. occasionally enters the cavern, and there is no doubt that the Big Spring of the Meramec, several miles distant and on the other side of a high rock ridge, is the chief water outlet of the second area.

The normal flow of the spring is about 60 000 000 gal. per 24 hours. A year's daily record of temperature showed a variation of about 2° Fahr., which proves that it is ground-water. At the time of the visit, about an hour after the first stream was forded, several engineers agreed to estimate the flow at 250 000 000 gal. per 24 hours. The water was roily, but fairly potable, being much the same as the water then supplied the citizens of St. Louis after sedimentation (since 1904, the St. Louis water has been clarified). The original forest, which was not dense, was cut 25 years or more ago for timber and for smelting-furnace fuel. Nature seems to be indifferent as to reforestation. The humus is very thin, but the soil and subsoil are absorptive sponges, probably not less than 60% of the precipitation being stored.

The third stream, known as the "Water Fork of the Meramec," has no special feature to distinguish it from other streams coming from a rugged country whose hilltops are the remnants of a denuded plateau. The valleys are narrow, with numerous springs, the rivulet tributaries bring in fragments of disintegrated rock to be worn down by attrition into gravel and sand for the big city below. At the time of the visit, two hours after the spring was reached, the flow was taken to be about 400 000 000 gal. The water was of a gray turbidity, but became potable after 5 min. subsidence in a vessel. Soil wash was not seriously in evidence. This area has been deforested for timber and furnace fuel. The land ownership being largely held by the Iron Company, the population is sparse and not given to agriculture. The place rock is sandstone above and flinty limestone below, readily disintegrated. The humus is of fair depth on the plateaus and thin on the hillsides. The conditions are favorable to absorption; probably 50% of the precipitation would be a fair estimate.

The intensity of rainfall may be said to vary from a Scotch mist to a cloudburst; the run-off varies accordingly. The absorptive power of subsoil and rocks may vary from nothing to totality, and the run-off inversely. If the subsoil below the humus is impervious, crops may start, but must perish; if pervious, capillary action and roots of plants recall much moisture from underground storage, but a very large part sinks below reach and feeds springs more or less remote.

If one regards local run-off as the end, underground water is to him a dead loss; if he takes a broader view, it comes back to its place among available resources.

In the locality used by the writer as an illustration, there is fairly good basis for the idea that the ground-water gets back to the streams within the areas. The locality is in the "Ozarks," and probably is fairly representative of broken country in low mountain districts.

Mr. McMath.

The writer does not belittle evaporation and local run-off. He brings underground storage forward that it may have its proper place in the consideration of the vital question.

Considering the subsoil and underlying rocks as a sponge lying below the humus, the influence of forests on stream flow depends at least partly on whether they hold the water of rains and melted snow within reach of the sponge longer than denuded waste lands or cultivated fields. An infinite variety of conditions must affect the question; the only answer that may be given is an averaged result.

The author, in the first of his seven summing-up propositions, says:

"The bed of humus and débris that develops under forest cover retains precipitation during the summer season, or moderately dry periods at any time of the year, more effectually than do the soil and rocks of deforested areas similarly situated."

The writer is content to accept this statement as the grand averaged fact, and thinks it a verdict in favor of forests.

The conservation and utilization of Nature's resources are the special province of engineers. Now that the subject has come to the front, engineers would be very remiss if they failed to press forward in the discussion. They should not surrender the field to the horde of fakirs who rush into any discussion which promises to receive popular attention.

As a check and antidote to the follies of fakirs, Colonel Chittenden's paper and its discussion are valuable and timely.

Mr. Labelle.

H. F. LABELLE, M. AM. SOC. C. E. (by letter).—In point of timeliness and completeness this paper is *facile princeps;* the question of the influence of forests on the regimen of rivers through the control of rainfall has been presented to the Society in a most exhaustive manner. The paper brings this matter, which has assumed a national importance, before a body of men who, it is to be hoped, will discuss it exhaustively, and there is no doubt that the net result will be a clearer understanding of the complicated problems involved, which, so far, have for the most part remained without adequate solution.

The most natural thing to do, in investigating the value of this theory, as advanced by the votaries of reforestation, is to confront it with the facts; if it explains all or a great majority of them, it can be confidently accepted; if it does not, it is not tenable. In order to investigate the matter the writer submits Table 15, in which he has arranged by decades the high waters given by the author in Table 1. The available data from the Susquehanna and Schuylkill water-sheds have been added. The last two water-sheds have been selected because, in the first, deforestation has been progressing at a high rate since the Fifties; in the second, little or no deforestation has occurred during the last 40 years. The figures in Table 15 are the means of the author's figures for each successive decade; other periods are shown in brackets.

TABLE 15.

All Figures are in Feet, Except for the Schuylkill, where Inches Over the Reading Dam are Given.

Decade.	Years.	Mississippi.		Ohio.			Tennessee.		Missouri.	Connecticut.	Susquehanna.		Schuylkill.
											Harrisburg.		Reading.
		St Paul.	St. Louis.	Pittsburg.	Cincinnati.	Louisville.	Chattanooga	Florence.	Kansas City.	Springfield.	High water.	Low water.	High water.
1st	1848-1857	.....	(1838-55) 31.2	25.1	.....	.....	.....	.....	.....	.....	.....	.....	.....
2d	1858-1867	.....	(1856-67) 26.8	24.3	49.7	27.3	.....	.....	(1844-78) 21.3	16.1	.....	.....	.....
3d	.....	12.6	25.6	22.2	48.7	25.1	.....	24.3	.....	.....	.....	.....	(1880-87) 6.64
4th	1878-1887	11.4	27.6	24.6	54.1	30.3	35.0	22.0	19.8	14.4	(1891-98) 16.4	0.58	7.87
5th	1888-1897	10.5	27.1	25.4	48.6	23.9	33.5	20.4	19.8	15.3	15.9	0.89	6.89
6th	1898-1907	10.8	25.5	28.0	53.1	28.3	31.5	20.0	24.1	16.9			

Mr. Labelle.

Mr. Labelle.

From the Fifties to the early Nineties the lumbering operations on the Susquehanna were very brisk, and enormous quantities of square timber were taken down to tide-water. Many mills, especially in the Williamsport district on the West Branch of the Susquehanna, have also been busy transforming the forests into lumber. The flood of June 2d, 1889, which coincided with the flood at Johnstown, Pa., brought to tide-water millions of logs, which occurrence made clear the vast extent of lumber cutting in progress in the upper part of the water-shed. Since 1895 square timber rafting has ceased on the river, but the manufacturing of lumber and the consequent deforestation are still progressing at a rapid rate.

As to the Schuylkill River, E. F. Smith, M. Am. Soc. C. E., General Manager of the Schuylkill Navigation Company since 1865, states that little or no deforestation has taken place in the water-shed during the last 40 years, and that the Schuylkill valley is largely a farming and not a densely wooded district.

As the low water at Harrisburg, on the Susquehanna, has not been influenced by engineering works, the average low water for the last two decades (1891-1908) has been introduced in Table 15.

Bearing in mind that deforestation has progressed in all the water-sheds except the Schuylkill from the early decades to the present time, it will be seen from Table 15 that the floods have increased in some rivers and decreased in others. In the case of the Ohio, at Pittsburg, the mean of the floods (retrogressing from the third to the first period and progressing from the third to the sixth) has increased in about the same ratio. Comparing the Schuylkill for the fourth and fifth decades with the Ohio for the fifth and sixth decades, there is a greater increase in the first than in the second case; now, if the increase in the former cannot be attributed to deforestation, because no deforestation has taken place, why should it be in the second case? There is certainly no uniformity in the figures: they tend to show that deforestation is not the paramount factor in the causation of floods.

As already stated, the natural features of the low water on the Susquehanna have not been disturbed. The zero point of the Harrisburg gauge was placed at the low-water mark of 1804. This gauge was established in 1890. According to the theory here discussed, and after extensive deforestation of the water-shed, low waters should be much lower than they were 100 years ago. The fact is that the water at Harrisburg went below zero of the gauge only once since 1891 (−0.04 in 1900); in 1895 it went down to +0.04; all the other readings are above 0.16, and the means for the last two decades are as shown in Table 15. The low water since 1891 has apparently been on the increase. Here also, at first sight, the theory fails to explain the facts. The writer says "at first sight" because it is quite evident

Mr. Labelle. that other factors, like rainfall, its distribution, and the condition of the ground-water, may mask the effect of forests, and that a thorough analysis of these other factors is necessary before the real effect of deforestation becomes apparent.

It is believed that Mr. Leighton, in his remarks on the Tennessee River, has gone to the heart of the whole question, and that rainfall has to be considered in conjunction with deforestation. The writer also believes that the condition of the ground-water is the governing factor in low stages. This question has already been taken up by the Forestry Bureau, and diagrams have been made for a number of streams. If these diagrams show that neither the rainfall nor the condition of the ground-water can account for changes in the run-off, the theory of forests and stream flow will be materially strengthened. It is to be hoped that these diagrams, or, at least, the results obtained from them, will soon be published, and that they will be for a great variety of rivers in different parts of the country, including rivers having water-sheds which have suffered little or no deforestation. It is much to be desired, however, that this work be done by disinterested parties. The question of obtaining correctly the total daily or monthly rainfall in a water-shed from a few widely scattered stations is no easy task; it is strongly dependent on the judgment and experience of the computer, and, obviously, he should be free from preconceived ideas.

Mr. Pinchot has mentioned the importance of forest cover as increasing ground-water storage and the consequent increasing of low-water stages. It is believed that there are other factors of much greater importance than forest cover in the creation and conservation of ground-water. A comparison of the minimum run-off of that part of the Susquehanna water-shed above Harrisburg with the minimum run-off of the Octoraro Creek, a tributary of the Susquehanna, draining a water-shed of 217 sq. miles near tide-water, devoid of forests and under a high state of cultivation, while the country above Harrisburg is only partly deforested, gives the following results:

Year.	Susquehanna River above Harrisburg. Minimum run-off per square mile.	Octoraro Basin. Minimum run-off per square mile.
1897	0.19 sec-ft.	0.63 sec-ft.
1898	0.21 " "	0.83 " "
1899	0.15 " "	0.80 " "

The factors favoring the Octoraro Basin, which is in the alluvial plain at the head of Chesapeake Bay, are porosity of ground and flat slopes, while the water-shed above Harrisburg is in the hills and the ground has less retentivity. Even if the forests above Harrisburg had remained intact, it is difficult to conceive that low-water run-off

per unit of area in that part of the water-shed would have reached the figures given for the Octoraro Basin. The foregoing statement would corroborate the author's 7th proposition.* Mr. Labelle.

The Bureau of Forestry has investigated different water-sheds, from time to time, for the purpose of ascertaining the effect of forests on stream flow. These investigations can be divided into two classes: (1) Those carried out in adjoining water-sheds, both forested and deforested; (2) those carried out in a given water-shed before and after deforestation.

The investigations carried out in the San Bernardino Mountains, California, belong to the first type. Mr. James W. Toumey,† in recording the results of the above, prefaces his tabulation as follows:

"There are so many complex conditions influencing the flow of streams that it is extremely difficult to determine the effect of forests on run-off by the comparison of the discharge of streams on forested and nonforested catchment areas. It is believed by many that stream flow is so largely influenced by the amount, intensity, and character of the precipitation, the configuration and area of the catchment basin, the character of the absorbing medium and the underlying rocks, and the general climate, as well as the forest itself, that we shall probably never be able to measure quantitatively the influence of forests on the flow of streams by the comparison of forested and nonforested regions. Catchment areas differ so greatly in the features mentioned above that our most conservative and able investigators have been forced to the conclusion that 'in respect to run-off, each stream is a law unto itself.'"

The results of his investigations are summarized in Table 16.

TABLE 16.

Area of catchment basin, in square miles.	Condition as to cover.	Run-off in Percentage of Precipitation:			Run-off in June, in acre-feet per square mile.
		In December, 1899.	In January, February, and March, 1900.	Annual.	
0.70	Forested.	3	35	28	25 —
1.05	"	6	33	30	30 —
1.47	"	6	43	36	30 +
0.53	Non-forested.	40	95	69	0

The rainy season begins in December and ends in March. The precipitation is 46 in. for the forested and 33 in. for the non-forested areas. At first sight the results are all in favor of forests, except as to the total annual run-off, which is 69% for the non-forested and

* Page 281.

† "The Relation of Forests to Stream Flow," by James W. Toumey; a reprint from the Yearbook of the Dept. of Agriculture, 1903.

Mr. Labelle. only 33% for the forested areas. From the results Mr. Toumey concludes that the forests are beneficial, inasmuch as they tend to equalize the flow throughout the year. He does not say a word about the relative slope and porosity of the water-sheds; the precipitation is given, but its character is not mentioned. The influence of the different factors producing run-off should have been found before the percentage of influence due to forests could have been determined. This procedure in the above experiments would have made the results more convincing.

The investigation of the causes of the decreased flow of Rock River, Wisconsin, belongs to the second class.* The water-shed has an area of about 3 600 sq. miles, is slow-spilling, and has a comparatively high retentivity.

A good proportion of its swampy lands and small lakes has been drained; and the custom of laying tile and other drains and of cutting ditches prevails throughout the region. This has resulted in a more rapid delivery of the rain water into the streams. The rainfall has been decreasing since 1885. The forests have decreased from 75% to 30% of the whole area. Mr. Schwarz, the author of the pamphlet, states that the most obvious explanation for the smaller quantity of water annually carried by Rock River is the diminution of rainfall; he ascribes also a certain amount of influence to the draining operations above mentioned. The principal body of water which has been drained is the Horicon Marsh, at the upper end of the main branch of the river. This marsh was dammed in 1846 for water-power; it has an area of 73 sq. miles, and its catchment amounts to approximately 400 sq. miles, or one-ninth of the water-shed. Later, the dam was removed, and the tract was allowed to revert to its original state and was put under cultivation. In spite of the conditions just described, the pamphlet attributes largely to deforestation the reduction in the stream flow.

It seems to the writer that the conditions obtaining in the water-shed were well enough known to permit of making some kind of an estimate of the percentage of decrease of run-off due to:

1.—Smaller rainfall;

2.—Drainage of swamps, low lands, and the Horicon Marsh;

3.—Increased demand of cultivated lands;

4.—Deforestation.

The sum of the first three factors subtracted from the total decrease in run-off as computed from gauging operations would give the fourth factor, or the percentage of decrease due to deforestation. Until this computation is made, all estimates of this fourth factor are mere speculation.

* "The Diminished Flow of Rock River in Wisconsin and Illinois," by G. F. Schwarz; Bulletin No. 44, Bureau of Forestry.

Mr. Labelle.

Both Colonel Chittenden and Mr. Pinchot have gone to the water-shed of the Sacramento River* to secure evidence in favor of their views. Their conclusions are divergent. In the paper on the flood of March, 1907, on pages 296 and 297, is found the rainfall for both the American River and Puta Creek, the two streams selected for comparison. The divergence in the conclusions is caused by the use of different rain stations in the columns headed March 17th-26th. The author derives his average rainfall for Puta Creek from Stations 76 and 77, excluding the two others as not representing territory tributary to the run-off gauging stations. Mr. Pinchot objects to this, and by taking in Stations 74 and 78 and some stations outside of the water-shed (a procedure of doubtful orthodoxy, but the figures on the Cache Creek Basin were very tempting) he manages to get an average much lower than the author's, thereby turning the tables on the latter. The writer does not think it necessary to go outside of the Puta Creek water-shed for rainfall data. If the period from March 17th to 26th does not furnish sufficient information, the two water-sheds may be compared for the whole month of March, which is preferable for our purpose for it represents a greater percentage (70%) of the yearly rainfall. Table 4 of the paper cited gives the precipitation of both water-sheds for March, 1907. From Tables 13 and 14 of the same paper the total discharge for the month can be obtained. Table 17 gives the precipitation and run-off for each water-shed.

TABLE 17.

	Precipitation, in inches.	Drainage area, in square miles.	Total rainfall, in billions of cubic feet.	Total run-off, in billions of cubic feet.	Percentage of run-off.
American River	25.67	1 910	114	62	54.5
Puta Creek	19.12	805	36	13.45	37.4

The figures in Table 17 certainly do not favor forestation. It is fair to say, however, that they are not an argument against forests, because the percentage of snow in the American River water-shed is not known and cannot be estimated owing to the non-existence of rain and snow gauges in the upper part of the basin.

In his 5th proposition the author gives an important place to second growth; there is no doubt that second growth in Eastern forests tends to perpetuate or at least restore the conditions obtaining before the removal of the virgin forest, whether these conditions be favorable or not to the uniformity of stream flow. In the Southwest, however, in places, coniferæ compose the bulk of the forests, and deforesta-

* "The Flood of March, 1907, in the Sacramento and San Joaquin River Basins, California," *Transactions*, Am. Soc. C. E., Vol. LXI, p. 281.

Mr. Labelle. tion leaves the country as bare as the bluffs of Eastern Nebraska. On some of the hills, where thick forests existed 25 years ago, not a tree nor a bush can be seen; the second growth, owing no doubt to the scarcity of rainfall, has not materialized; there is almost no grass, and the ground is bare and sun-baked. Still the erosion is not remarkable from year to year, and is almost entirely confined to the stream beds. It is true to say, however, that floods have more violence now than before deforestation.

Silver City, a town in Southwestern New Mexico, about 8 miles from and on the eastern slope of the Continental Divide, was founded about 1870. Although the business part of the town was often flooded during the rainy season, no material damage was done until about 13 years ago. At that time the forests in the water-shed had been considerably reduced and a flood of unusual severity coming then destroyed several buildings on the main street, including a large hotel, and started to cut a new channel on the line of that street. The gulley is now about 50 ft. deep and 100 ft. wide in some places. The people of Silver City consider the occurrence a blessing in disguise, for it has confined the floods, and the town is now free from further damage. The people also believe that the deforestation of the water-shed has been the primary cause of the erosion, and it is really hard to believe that any other cause could have produced it. It is believed that this part of New Mexico is eminently well adapted to the gathering of evidence in the matter discussed herewith, especially as to erosion, owing to the favorable conditions of rainfall, slope, and soil, surface and subsurface.

We must not, however, give to soil erosion an importance so great as to induce us to believe that our highlands are surely, if slowly, being washed to the ocean. We can permit ourselves to doubt the imminence of this peril if we consider for a moment the Chinese Empire and its vast area feeding its millions of mouths. In spite of the fact that China has been deforested for hundreds, nay, perhaps for thousands of years; in spite of the fact that the quantity of material eroded from its surface has been sufficient partly to fill and discolor the waters of the Yellow Sea, without mentioning the enormous quantity of deposits brought into the China Sea; in spite of the high rate of rainfall and the destructive floods occurring in the basins of its rivers, the land is still able to feed a population five times as large as ours, and the end is not yet. No, let us rather believe that the husbandman, with the help of fertilizers, proper rotation of crops, and other scientific modes of culture, will be able to work faster than the destructive forces of Nature, and stay the progress of erosion. With the example of China under our eyes we are warranted in believing that our highlands will not cease to be productive for three or four thousand years; this should satisfy the most rabid devotees of the great-grandchildren

cult. The Chinese and also the Igorrotes of Northern Luzon prevent the erosion of their sidehills by building against them a system of terraces; some fine examples of this mode of construction can be seen in the Province of Lepanto-Bontoc, Island of Luzon. Mr. Labelle.

Enough has been said to show how insecure the foundation underlying the theory of forest and stream flow is at present. Further studies will probably bring out classes and indicate the kind of watersheds where forestation is beneficial. To accept the theory as it now stands, with its sweeping claims, would be both illogical and unwise. If the acceptance of this theory means the spending of millions in time and money, the country should be sure that failure to accomplish results will not confront future generations.

In reference to the system of reservoirs proposed on the Ohio River and its tributaries: If the advocates of the scheme expect to get revenue from the sale of water-power in the Ohio Valley, they will certainly meet with disappointment. This section of the country is blessed with an abundance of good coal, and it would be difficult to find anywhere a district where water-power is in less demand and will remain so for so many years. Should our Government wish to elucidate this matter, let a power survey be made of the whole valley and it will soon be found that the proposition is hopeless.

As regards the enterprise as a whole, the writer hopes that it will be agreed that nobody knows whether or not it is practicable, because nobody has ever tried to find out and gather the physical facts necessary to form an intelligent opinion.

The writer finds only one fault with the investigation of this matter which was initiated by the last Congress; the appropriations for this work should be largely increased to push it rapidly to completion. The whole water-shed of the Ohio should be investigated, proper structures designed, and different combinations of reservoirs effected; then the whole proposition should be submitted to engineers of national, if not international, reputation, and its merits and practicability determined on a basis of indisputable facts and data. The more complete and exhaustive are the studies, the less speculation will be required. If the scheme has to be rejected, let it be done as quickly as practicable, in order that local means may be adopted for the protection of flood-swept districts and the amelioration of rivers.

EMIL KUICHLING, M. AM. SOC. C. E. (by letter).—This difficult subject has been presented by the author in a very clear and forcible manner, and gives the results of his careful observations and long experience with extensive projects for the conservation and regulation of the discharge of many natural streams. The ground covered, however, is so broad that discussion must necessarily be limited to the consideration of only a few of the various features involved. Mr. Kuichling.

Much has been written during the past fifty years on the meteoro-

Mr. Kuichling.

logical influence of forests, but the conclusions reached are often discordant, owing to the obscurity of our knowledge of the various factors that enter into the problem. Some writers have laid stress on the mysterious properties of trees, singly and in groups, as exciters or conductors of electricity; others have given attention to the complex thermal influences of vegetable life; another class has studied the purely chemical actions of foliage; while a fourth class considers only the geological and hydrological relations, or the rainfall and run-off as commonly expressed and understood. These latter relations, however, involve all the others, so that in reality run-off is the resultant of a variety of physical forces, most of which are still almost unknown.

The familiar factor called rainfall or precipitation is by no means easy to measure, or even estimate, with accuracy on a large drainage area. Its magnitude varies in almost every storm, both with the position and altitude of the rain-gauge and with the direction of the wind. Gauges placed only a few miles apart at the same altitude usually exhibit very considerable differences in the quantity of water caught, and these differences increase greatly in a mountainous region, especially on opposite sides of a high range. Still greater do such differences become when dealing with snow. In conjunction with one of the most skilful observers in the U. S. Weather Bureau, the writer once undertook to measure the depth of snowfall during two winters, but in no instance did the observations agree, either in respect to depth or weight, at several different points in the same city; neither did the differences balance even approximately in the course of several consecutive months.

In view of these difficulties of estimating the approximate depth of atmospheric precipitation on a relatively small and nearly level urban area with a number of favorably located gauges, it is easy to understand how much more difficult the task becomes in the case of large drainage basins presenting a great variety of surface and altitude, and having thereon only a few places of observation.

Numerous cases might be cited in our oldest and most densely populated States, where important river basins with areas of several thousand square miles have only two or three rain-gauges, whose records embrace less than twenty years; and plenty of cases occur where the observed run-off from adjacent tributary water-sheds of similar character in the same basin is widely different during a season of several months from apparently equal amounts of precipitation. Other instances also occur where the aggregate observed run-off during twelve consecutive months, from a mountainous drainage area of several hundred square miles, is greater than the reported precipitation thereon, measured at one or two stations.

But while there are probably serious errors in the estimates of our rainfall, as well as a woful deficiency in the number of places of obser-

vation, the available data for run-off are generally not in much better condition, due to difficulties of measurement and observation. It is rarely the case that the gaugings of a stream at the same stage of flow agree with each other in the course of several years, even when the channel remains unchanged, and in but few instances are accurate measurements made of high floods. It also seems to be necessary to change the rating tables of many river stations from time to time in consequence of altered channel or more reliable gaugings, so that comparisons of discharge at some particular stage in different years cannot be made without much tedious study. Such work is usually impracticable in the case of private enterprises and is seldom done for public purposes, but it is indispensable when endeavoring to ascertain the cause of variations in discharge. Mr. Kuichling.

It seems to the writer, therefore, that, with the scanty data now available in the United States, a sound conclusion cannot be reached in regard to the influence of forests on either rainfall or run-off; and that, until a much larger volume of accurate observations has been acquired, we must content ourselves with the more or less imperfect studies of the subject that have been made abroad. There is, however, no question about its importance from the point of view of national economics, and the writer hopes that the public interest taken in it will quickly lead to the needed enlargement of our Weather and Hydrographic Bureaus.

ROBERT FLETCHER, ASSOC. AM. SOC. C. E. (by letter).—The following facts have come within the range of the writer's personal experience and observation: Region: the upper Connecticut Valley at a point where there is a tributary area of about 3 250 sq. miles, north of Dartmouth College. Altitude of the country: from 380 ft. above the sea at the river level to 6 000 ft. in the White Mountains. Annual rainfall: between 30 and 40 in. Winter conditions: ground frozen from late November to the middle of April. Surface of the country: river bottoms, narrow valleys, generally steep hillsides; probably one-quarter or more in forest which is mostly recent growth excepting about the head-waters of streams in the extreme north. Furthermore, the writer is interested in the work being done by Dartmouth College, under the supervision of its forester, in systematic forestry applied to the College Grant which comprises about 40 sq. miles near the head-waters of the Connecticut River. Also, as an official of the Hanover Water-Works Company (which is the College and Village precinct in a joint corporation), he has supervision of about 2 sq. miles, the entire drainage area tributary to the reservoir which furnishes the water supply. His period of personal observation extends over thirty-six years. Mr. Fletcher.

As to forestry conditions in this region, the following facts are undisputed: The primeval forest has long since disappeared, excepting

Mr. Fletcher. on the slopes of the northern mountains and in some very rare small holdings farther south. Lumbering has been going on incessantly for two or three generations, resulting in "drives" of logs down the river amounting annually to 60 000 000 ft. or more. Every farm, since the settlement, has had its "wood lot" as the source of fuel. Since the railroad era, 75 years ago, the demands on the forests for locomotive fuel have been very great, until, within 25 years, the coal-bin has displaced the railroad wood-pile. Latterly, to the great cuttings of the lumber companies have been added also the large cuttings made by owners of paper mills for the manufacture of wood pulp. Both of the latter were principally concerned in getting out the pine, poplar, basswood, and spruce, leaving a large amount of the hardwood undisturbed excepting for the inevitable breaking down of trees and the accumulation of great quantities of slash. Last of all have come the agents of a great concern (one or more?), the so-called "Match Company," who, offering to the farmer, for the growth on his woodland, a cash price (which is often far less than its real value, but is a goodly sum to the rural owner), buys it all and makes a clean sweep. The farmer, to be sure, has his land left, but most of it will be worthless, until, in perhaps 80 or 100 years, it may produce another forest. Within the last 5 years it has become a familiar sight to see prominent hillsides up and down the Connecticut Valley almost entirely denuded of their timber growth.

With regard to the erosion in such cases, it may be said that all depends on the nature of the soil and the slope. Heavy rains undoubtedly make the rocky slopes more bare, because the thin soil dries out quickly without the protection of the foliage. The heavy soils are more tenacious, and allow the rapid development of new growth. The sandy terraces are frequently badly washed by rain and scored by wind, because they dry so quickly without the protecting cover.

According to the testimony of the oldest inhabitants, there is probably more woodland throughout this section of country than there was fifty years ago. In all directions, old pastures are growing up to white pine, whenever "seed-trees" are favorably situated, and it is surprising how rapidly these trees grow—when they have made a good start—from the sixth year after seeding. Young pines will increase in height from 1½ to 2 ft. annually, and, after the twentieth year, have been known to add 4 ft. to their height in a single year. After that period, also, the annual increase of bulk is about 10 per cent. By systematic work and some outlay, an individual, if he has patience and years enough before him, may do considerable reforestation by raising and setting seedlings; but it is the writer's experience that Nature, if left to herself under favorable conditions, will easily outstrip him three or four acres to one, especially with a little assistance in transplanting, where the natural seedlings are bunched too much.

Noting briefly now the author's numbered conclusions:

Mr. Fletcher.

(1) The moderating and equalizing influence of forests on the run-off of ordinary rainstorms is a fact too obvious to be questioned. We must not, however, belittle the absorbent and retentive power of tillage and grass land under proper conditions of cultivation and slope.

(2) The author's second proposition is quite confirmed by the writer, who has tramped for miles over the drainage area of the reservoir in the height of heavy rainstorms, and found the saturated woodland shedding the rainfall in swift and furious streams, even more rapidly than the meadows where grass was growing.

(3) The author's proposition concerning run-off in summer the writer would apply to woodland and open country alike. Throughout the summer and autumn, when the grass, and crops, and trees, alike absorb moisture from the soil, heavy rains in the reservoir district produce but little effect on the level of the pond. In this case, the area of the reservoir (34 acres) is about one thirty-eighth part of the drainage basin, and the whole district is underlaid by an impervious boulder clay, so that nearly all the seepage eventually reaches the pond. In winter, however, the pond level rises quickly, even with moderate thaws or small rainfalls.

(4) The author's proposition concerning the effect of forests on snowfall to aggravate the flood discharge of rivers is not true in this region. Snow always remains in the woods late in the spring (except among young deciduous growth on the south exposure), and disappears gradually during April and May. Furthermore, the ground in the woods freezes much less than that in the open, and probably in spots allows percolation of water from the snow more or less throughout the winter; for, in the reservoir under observation, the surface level has been known to rise throughout the winter notwithstanding the draft upon the reservoir. (A temperature of 20° below zero is commonly experienced during three months of the winter.)

(5) Soil erosion depends so much upon circumstances, as already noted, that we may pass the question here.

(6) As to climatic conditions in this region, there has been no marked change in the mean annual precipitation since 1835, when the keeping of systematic records began. Of course, after the past season of phenomenal drought, by which we are more than 10 in. short of the average during the past year, the most ardent faith in statistics is likely to waver a little, as though some change were impending; but the records show that our forefathers had similar experiences and probably similar misgivings.

Period of 21 years.	Mean annual precipitation.
1835 to 1855	40.77 in.
1866 to 1886	30.63 "
1887 to 1907	36.43 "

Apparently, there is a gradual decrease, in the long run(?), but we can judge better 20 years hence.

Mr. Fletcher. Furthermore, as to river floods, there has been no noticeable increase. In fact, the highest flood that the writer has ever seen occurred about 25 years ago, and was considerably short of the height of the record flood of 1869, which wrought destruction throughout New England. Mill operators along the Connecticut also testify that there has been no noticeable change in the flood extremes. If anything, the flow has been more uniform in recent years. This last statement is the only comment the writer cares to make on Proposition 7.

For another case in point, it is proper to cite the experience of a private water company which supplies the village with a very pure spring-water drawn from a series of wells on a wooded hillside about 2 miles distant, and delivered through a 2-in. pipe to about 160 takers. This supply has not failed throughout the phenomenal drought of the last six months, and it is believed that it has been conserved by carefully maintaining the forest growth on the company's reservation.

Finally, extreme statements on both sides should be avoided, and the facts, when carefully ascertained, should be rightly interpreted. If it is true, as has been stated, that the fire gets more than the axe, then the lumberman naturally wishes to rescue the wood for the use of man. On the other hand, in virgin forest, the fire is not so apt to make headway, especially with a little care; but the vast areas obstructed by slash will always be subject to permanent destruction, until decay has done its work.

As to the question of cause and effect, the distinguished curator of the Arnold Arboretum has said, "If you have rainfall, you will have forest; no rainfall, no forest." It is an incontestable fact that the smaller streams of our side valleys not only have less regular flow, but have less annual discharge than in the days of the grandfathers. Ruins of mills and dams may be found on mountain streams where the attempt to establish a water-power to-day would be ridiculous. It is a fair question whether the country has been undergoing a gradual desiccation since the glacial period, irrespective of the question of annual rainfall. A fair interpretation of experience and observed facts leads to the inevitable conclusion that extensive and continued denudation of our forest-clad hills and mountains without continual and successful reforestation would be an immeasurable calamity, and that, putting aside argument or disputed points, we will make no mistake in all reasonable endeavor to conserve to the utmost the protected conditions about the head-waters of our streams and in the higher valleys, which we have inherited from the past.

Mr. Snow. J. P. Snow, M. Am. Soc. C. E. (by letter).—The paper is timely as an offset to the present absurd statements in regard to the calamities overshadowing us on account of changing forests to cleared land. An experience of more than 40 years in Central and Northern New England leads the writer to agree, in the main, with the essence of

Colonel Chittenden's position. Some features of the paper, however, may, perhaps, be made to mean more than was intended. Mr. Snow.

Conditions vary for each locality, and a statement that is true for one place may not hold in another. The author well says that no fixed rule can be upheld for all localities and conditions. What follows must be considered as pertaining only to that portion of New England between the latitude of Boston and the Canadian line.

Certain vital elements of the problem have not been mentioned in recent discussions, as far as the writer has observed. That forests evaporate an enormous quantity of water from foliage is proved by the water level in swamps becoming higher after a heavy growth has been cut off. On ordinary upland forest this evaporation tends to lower the subsoil water more than the growth on open land. Surface springs and running streamlets, on the other hand, are protected from evaporation by the shade of the forest, and stand a better chance to persist through a hot summer than if in the open. It is not surface water, however, that principally feeds our streams during ordinary or low-water periods. It is subsoil water reaching the streams below the water surface. Many times wells and pits have been sunk near streams with the idea of getting the advantage of filtration through a few feet of earth, and, behold, the supply was all from the side farthest from the stream. The greater part of New England is covered with a blanket, from 5 to 15 ft. thick, of interglacial gravel resting on subglacial till or ledge. Deep bank cuttings all over the region show water oozing out at the top of the impervious stratum below the gravel blanket. This natural reservoir is practically independent of surface cover.

In long-continued rains, when the ground is not frozen, the run-off is practically the same from open as from forest-covered land, with the following exception, in connection with freshet effects: Forest streams are generally choked with driftwood, and sometimes very formidable jams occur, which spread devastation when they break. A stream may even be turned from its course when one of these jams holds permanently, as is indicated on the Ammonoosuc River, in New Hampshire, a few miles above the Village of Littleton. These obstructions do not increase or decrease the total run-off, but they do have a marked effect on the possible amount of damage that high water may do.

In the case of moderate rains, the absorbent action of open and wooded land is probably very nearly equal, as a whole, with the balance in favor of the open land, if the ground is not frozen. New England grass-land, with its thick mat close to the surface, and with stalks and roots leading down into the soil, is certainly almost ideal as an absorbent. Deciduous forest, on the other hand, covers the ground with broad leaves that act like shingles to keep the water

Mr. Snow. from the soil. Fine needles act in much the same manner. Spruce, hemlock, cedar, fir, and larch furnish an absorbent bed, but it takes more than a gentle rain or common shower to get through the dense foliage of these trees before it is dissipated by evaporation; but little water reaches the ground, under these conditions, except that which runs down the trunks. Where the surface is covered with a thick moss growth, water is absorbed and retained better than on grass-land, but this condition obtains but sparingly in true forest.

As to forest effects on snow-melting: The author's position is certainly correct under certain conditions that are always possible, but seldom occur in the region here considered. Those who are responsible for railroad way and structures always dread a heavy burden of snow in the woods during late spring. If there is much snowfall, the normal condition is that a heavy burden will remain in the forest after the open ground is bare, except for drifts. If, under these conditions, a long rain occurs after a day or two of cloudy warm weather, the whole burden in the woods will go. Frequently the quiet reaches of the streams will still be covered with heavy ice, and all sorts of things may happen.

Snow upon open land frequently melts largely from the bottom, if the snow blanket comes on early enough to prevent deep freezing of the ground and remains on continuously through the winter. In this case the water is very largely absorbed by the ground. In heavy forest, on the other hand, this does not occur to nearly the same extent. Although the ground seldom freezes at all, the bed of humus, leaves, or moss, seems to act as an insulator to prevent the ground heat from melting the snow. Snow sometimes evaporates without melting, if the air is unusually dry for a long period. Water, as we know it, is a meteorological phenomenon, and meteorological conditions govern the whole problem. Forest effects are very subordinate and occasional, as far as ordinary run-off is concerned; under special conditions, such as described, the effect of large forest areas is distinctly bad.

In one way, not noted by the author, forests conserve the low-water flow of streams of moderate size, especially that of mountain streams on rocky beds. The evaporation on a hot summer day from a stream flowing over a bed paved with cobbles exposed to the full glare of the sun is very great. The cobbles and boulders are alternately wet and dry from the splashing of the water and the drying effect of the sun. Many miles of streams exist in New England that are now exposed to these conditions, whereas a century and a half ago they were largely protected from the sun's pumping effect by overhanging trees and water-loving bushes along their banks. This feature of shade and exposure probably measures the principal advantage of forest cover over open land in conserving stream flow.

Mr. Snow.

Soil wash may be due to gullying the surface, or bank erosion by streams. The first, such as is common in the Piedmont Section of the Southern States, is almost unknown in New England. The latter occurs both in forest and open land. Torrential streams generally keep their banks intact in both forest and open, except when jams occur in the timber. On quiet reaches the bottom land in heavy timber is usually a network of sloughs, sand-bars, snags, and swamps due to drift. In the open, banks are frequently cut at the bends, and disastrous cut-offs sometimes occur. A fringe of small-growth trees and bushes along the banks of the streams, through level land, is a great protection against this class of damage.

The greatest damage from erosion is due to sediment deposited on arable land or in bars which tend to divert the stream and spread it out into shallows. Without doubt the sudden removal of forest growth from a water-shed may result in erosion that will be pernicious to the land below, as will any disturbance of the existing equilibrium. Sawdust from lumber mills, poisonous sediment from paper and woolen mills, waste from tanneries, drainage from cities, wash from highways and streets, and the various encroachments of grasping abutters will destroy the regimen of a stream unless it is properly controlled by competent authority. Once a stream in the open is choked and spread out into shallows, its waters are exposed to the pumping effect of the summer sun, and a small dry-season run-off will follow.

Serious erosion sometimes occurs from the undercutting by subsoil water from adjoining land when timber fringes are removed from stream banks. Such removal can hardly be called deforestation, but some of the minor features of the relation of wood growth to streams have more actual influence on the question at issue than the sponge theories of our friends, the lecturers. The sponginess of the thin-soiled rocky hillsides of New England is a negligible quantity.

As the author states, the amount of stream flow depends on the amount of precipitation, and forests are not the cause, but the natural effect, of abundant precipitation. This effect, if correctly spelled out, will read that mighty forests are produced by heavy precipitation because they are the most rapid dissipators of the superabundant moisture. Replace the tree growth of the Coast Range in Washington and British Columbia with close-cropped lawn grass, and the streams and rivers will carry much more water than they do now.

In a half century the streams, springs, and wells of New England have not been as low as they have been in 1908, although the area in tree growth is much greater now than 50 years ago. The reason of the low water, however, is simply the lack of rain.

The proper objects of forest conservation are well set forth by the author. His views accord with those of the writer except, perhaps, in the matter of devoting convenient lowlands to timber growth.

Mr. Snow. The scheme, advocated by many, of reserving enormous tracts of land for forest growth exclusively is all wrong. To prevent cutting in primeval forests is still worse. Matured trees make but little growth, and nearly all timber native in Appalachian regions is better in second than in old growth. Primeval forest shows lack of civilization, and large areas of it will lead back to uncivilized conditions among its denizens, be they men or beasts.

The true way to make forest conservation a benefit to the people is to encourage the growth of valuable timber in small areas scattered all over the farming section. In New England the northerly slopes are almost invariably better adapted to tree growth than to pasture or to cultivation. Add to these the high lands too rocky or thin-soiled for farm use, and we have a sufficient area for timber. It is probable that this is just what the author means, but his statement is capable of being interpreted differently.

Land that can be cultivated profitably for field crops should not be wasted on forests. There is an abundant area in New England that cannot be so cultivated without going to the high peaks of the White Mountains or their slopes, which, forsooth, are mostly above the tree-line or too near it for the profitable growth of timber. Small areas, as advocated above, will not endanger streams by driftwood or quick spring floods; nor will they foster such awful fires as large tracts actually invite.

Reforestation, to be successful, must rest on an economic basis. The greatest handicap to forest raising to-day is taxation. In the region considered, real estate is heavily taxed, especially that controlled by non-resident owners. If taxes on land devoted entirely to tree growing—where an earnest effort is made by the owners to grow suitable trees—could be assumed by the State or Nation until revenue of some kind is derived from the land, a substantial and wholesome impetus would be given to the work.

Mr. Johnston. CLARENCE T. JOHNSTON, M. AM. SOC. C. E. (by letter).—All who are familiar with the forested mountain regions of the West will agree with Colonel Chittenden in his conclusions. Possibly there are localities in the East where forests have the influence on stream-flow which has been attributed to them by popular rather than scientific authorities. Several discussors refer to the days of their childhood when forests were found on every hand, when streams furnished a steady flow, and when floods were not common; but they do not supply any data from which to judge as to how much cultivation has taken place since the forests disappeared, and what kind of vegetable growth has taken the place of the forests. Neither do they furnish any information relative to the rainfall during the years covered by their observations, the character of the drainage area, the kind of soil, the slope, etc. In the absence of this information, it is difficult to understand how

those who read are to ascertain whether or not such conclusions are based on fact or fancy. Mr. Johnston.

Precipitation problems have been studied by the officers of the United States Weather Bureau for many years, yet the writer has been unable to find, in any of their reports, anything which would lead to the belief that forests have any appreciable effect on rainfall. Until this important branch of the Government service shows that there is some relation between forests and precipitation, men with scientific attainments will not be in haste to conclude that forests are a great factor in influencing rain and snowfall.

The writer has spent many months in the mountains of the West, and there the great problem is, not to prevent floods, because these are always of but local importance and of no great consequence, but to obtain the largest volume of water possible during the season when it is needed most for irrigation. Eastern streams are utilized for navigation and for power, as well as to furnish water for domestic purposes, but the problems in the West are different, because the needs and purposes there are different.

The writer's convictions have been established by observations and measurements covering a period of twenty years, and any one who doubts the truth of Colonel Chittenden's conclusions in reference to the timbered areas in the mountains of the West, should visit any of the numerous ranges in the spring before the snows begin to melt. He will find the timbered areas covered with a blanket of snow. The bleak mountain tops above the timber line will also appear to be covered, but as he ascends the mountains he will find that the snow on the high rocky slopes lies in depths varying from a few inches to 30 ft. and more. It will be found that it is warmer on the treeless slopes than it is in the forests while the sun is shining directly upon them; and when the sun is obscured, it is warmer under and among the trees.

As the weather grows warmer, it will be found that the snow lying thinly on the exposed treeless areas disappears first, and the great drifts surrounding these areas of light snowfall above the timber line show but little tendency to change. The snows in the forests, being distributed in uniform depth, gradually settle, absorbing the water that results from melting, and freezing at the surface each night. Later in the season, the great drifts above the forests settle gradually and the streams are largely supplied from areas where the snowfall has been from 1 to 3 ft. in depth and where melting is not delayed by the shade of the trees. As the season advances, and some time between May 1st and June 15th, depending on the lateness of the spring, the snow in the forested areas begins to melt, and, as it is practically uniform in depth, the entire timbered area furnishes water to a stream and its tributaries at the same time, and,

Mr. Johnston. owing to the saturated condition of the snow, it disappears within a few days. The floods which occur in the West come from the forested areas regularly each year. They do more damage to irrigation works by carrying timber which lodges in dams and head-gates than by high water alone.

If one considers the character of the timber grown on the mountains of the inter-mountain region, and estimates the volume of water necessary for the production of this timber, it becomes an economic question whether or not the farmers can afford, ultimately, to permit the growth of trees to the injury of the total available water supply. Before many years, all the water of our streams will be stored and held until the irrigation season begins. When this occurs, agricultural growth will be hampered unless all the water that can be obtained for this higher use can be made available. As every irrigator plants trees, this transition will tend to increase rather than to diminish the forest area and the available timber supply.

By July 1st, the snow has disappeared from the forested areas, and the water supply thereafter is derived from occasional rains and the great snow banks in the mountains. Later than July 1st, it is possible to find small quantities of snow here and there in the forests, but, although the writer, for twenty years, has been searching for snow in the forests during August, the month when water is needed most for irrigation, he has failed to find it.

It is fortunate that this important subject is receiving some intelligent study, and that discussions are being submitted which deal with facts rather than with boyhood dreams and theories unsupported by experiment or scientific observation. The Government's forestry work should not be affected in any way by the solution of the problems considered in this investigation. If the forestry service rightly has a place under the National Government, this place is assured, because its value to the public must depend on the protection it affords to forests and the timber supply. It is not necessary for that department to attempt to perform everything, and particularly to make claims which would lead one to believe that trees do not belong to the vegetable kingdom, in that they conserve more water than they need in their growth and development.

Mr. Pinchot. GIFFORD PINCHOT, ASSOC. AM. SOC. C. E.—In discussing the influence of forests on stream flow, it is unlikely that we will ever have a better statement, in certain respects, of the case against the forests than that which Colonel Chittenden has made. It has been restated time after time, under different conditions and by writers of different nations. This is, perhaps, the best statement ever made in America; therefore, it is particularly important, as far as facts are known, that the discussion should be as complete as possible.

Mr. Pinchot.

The essential point to be considered in the discussion of the relation of forests to stream flow is this: What are the functions of the forest floor in the distribution of fallen rain?

Colonel Chittenden quotes at some length from the testimony of the speaker before the House Committee on the Judiciary, given February 27th, 1908, as follows:

"I have in my hand here a photograph of a denuded hillside. After the forest has been removed rain falls on that hillside and runs off rapidly, as the water I drop upon the photograph does now, and disappears instantly (illustrating). If, on the other hand, I place a forest cover on the hillside, that is exactly analogous in texture and effect with this piece of blotting paper, and drop the water slowly upon it, we would find that, instead of running off slowly at the bottom, the water is held (illustrating with blotting paper). Part of it runs off, but, as soon as the absorbent quality of the paper or the forest floor has time to take effect, the water is kept and drips gradually for a considerable length of time off the hill into the stream. This is an exact illustration of the way in which the forest controls the stream flow on that hillside."

He continues:

"Mr. Pinchot should have completed his illustration. He should have continued to sprinkle the paper long enough and heavily enough to have saturated the paper completely in order to show that the water would then flow from the paper as rapidly as from the uncovered area; and he should then have explained that this condition represents what always happens in the forest in times of great flood. Then he should have sprinkled the paper intermittently in small quantities, and at such long intervals that the warm air of the room would evaporate all of the absorbed water, and that none whatever would flow away. He should then have explained that this condition represents what always takes place in the forest in times of great drought."

It is unfortunate that Colonel Chittenden should have stopped his quotation where he did. The paragraph continues unbroken:

"The water which was in this piece of blotting paper on that steep slope remaining on the surface in this way for a considerable length of time, has an opportunity to run down into the soil, which is made permeable on the surface by the decay from the trees. One of the best-known effects of the humus under a forest is to render the top layer of the soil permeable and therefore to allow the water to sink into this forest reservoir. Experiments made with the greatest care show that even a moderate bed of humus is able to hold some five times its own weight of water, and the water, being retained in that way, sinks gradually into the ground, and in this way the streams, instead of being made torrential, are made to flow much more regularly during the summer months. In other words, the effect of the forests, theoretically, from this experiment should be to diminish floods and maintain the low-water supply."

The speaker, on the preceding page of his testimony, had already

Mr. Pinchot. explained the function of the forest and the purpose of his illustration as follows:

"The effect of a forest on a steep slope is to cover that slope with leaves, rotten and half-rotten sticks, and other mechanical obstructions which prevent the water which falls upon that slope from running straight down below as rapidly as it would otherwise. In this connection it has, in the second place, the effect of permitting the water which falls on that slope, instead of rushing off rapidly, to sink into the mountains.

"Now the mountains are substantially great reservoirs of water, which cannot operate unless they are renewed from time to time by the rain that falls upon them; and the rain that falls upon them cannot get into the mountain reservoirs unless the surface of these reservoirs is in an absorbent condition. I can illustrate that to the members of the committee in a moment with a glass of water and a piece of blotting paper, as a definite illustration."

The illustration quoted above then follows.

Unfortunately, Colonel Chittenden has failed to gather from these statements what seems to the speaker to be their obvious meaning.

The illustration used is a fair description of one, but only one, of the essential functions of the forest floor, and due notice was given to that effect. The forest floor offers a physical obstruction to the rapid escape of water over the surface, and thus itself provides to some extent a small storage reservoir. Colonel Chittenden admits this influence for average conditions; indeed, it is a matter of such common observation as to be indisputable. The practical value of this influence may be little or much, depending on the character and amount of precipitation and the thickness of the undergrowth, decaying litter and humus on the ground.

There is, however, another function of the forest floor which in practical value far surpasses this one. The forest floor acts on the soil itself to multiply its absorptive capacity. The humus, which by natural action is being constantly mixed with the upper layers of mineral soil, greatly increases its receptive and retentive power, while the deep-penetrating roots also open passages through which water readily passes into the great reservoir of ground-water.

That Colonel Chittenden has failed, however, to consider this function is evident throughout his discussion. In giving an illustration, he says:* "Consider an inclined-plane surface, practically impervious to water." When it is understood that under the forest the surface is very far from impervious, and that, on the contrary, it is absorbent in a high degree, the argument is seen to be fallacious.

Failing to note this function of the forest floor, Colonel Chittenden misses entirely the greatest influence which the forest exerts on fallen moisture—that of changing surface drainage to underground drainage,

* Page 247.

and of replenishing the great underground reservoir from which the springs and streams are fed. Mr. Pinchot.

What is the importance of ground storage, which is so lightly passed over? Professor King has found that ordinary soils have a capacity of from 4 to 5 in. of water per foot of depth, or even more.* Ground-water extends to a considerable depth. Considering the earth masses which lie above the stream levels in mountainous regions, one may form an idea of what ground storage means to the permanency of stream flow. The ground-water is constantly in motion, is replenished entirely from the surface, and is easily disturbed by any change in surface conditions.

In certain regions where there is a very thick humus, reaching occasionally, as in the Adirondacks, a depth of 3 ft., it has an important storage capacity; but the capacity of the humus is always insignificant compared with that of the ground. The mountains themselves are the chief reservoirs, and the principal function of the forest, so far as water is concerned, is to keep the surface soil permeable, so that these reservoirs of ground-water may be regularly and bountifully replenished. When the importance of the forest to ground storage is once realized, a very large part of Colonel Chittenden's argument is seen to rest on a fundamental misconception.

While admitting that for average conditions the forest bed has some retentive influence, the author hastens to say emphatically that "it is not true for extreme conditions—great floods and excessively low waters."† He further says:‡

"When a period of heavy storms occurs, spreading over a great area, continually increasing in intensity, the forests, by retaining some portions of the earlier showers and paying them out afterward, do produce a general high condition of the river which may greatly aggravate a sudden flood arising later from some portion of the watershed."

This curious conception seems to have taken root: Assuming, for example, that the humus is able to hold 1 in. of rainfall; then, when a later storm of 4 or 5 in. comes on, not only the 4 or 5 in. of the storm runs into the streams, but also the 1 in. which was there before. Thus the storm itself would have destroyed the storage capacity of the forest floor; an assumption which doubtless Colonel Chittenden will repudiate at once, when his attention is called to it.

The speaker was quoted as saying that the increase of rainfall due to the forest is about 10 per cent. That figure was taken from the estimate of Dr. Ebermeyer who, perhaps, has studied the influence of mountain forests on precipitation as carefully as any one else.

* F. H. King, Nineteenth Annual Report, U. S. Geological Survey, Part II.
† Page 247.
‡ Page 249.

Mr. Pinchot.

The theoretical argument is overwhelmingly in favor of the contention that mountain forests do cause rain; and a reasonably correct view of that contention may be reached by taking an extreme case.

Take a heavily wooded water-shed, rising from the sea, as for instance in California, with prevailing on-shore winds during certain seasons. There are two things which lead one to suppose theoretically that the rain which does fall, under these conditions, should fall. One is the progressive cooling due to the air being forced into a higher altitude, resulting in a change in the amount of water vapor which the air will hold. The other is the fact that over the forest there exists a comparatively cool stratum of air, for some distance up, as has been ascertained by definite observations. We should, therefore, expect that a rain-cloud, passing from the sea over such a mountain range, would be inclined to drop its rain; first, because it was forced to cool itself by rising in height, and, second, because it met cool air above the forest. What would be the case if that same slope were deforested? The same influence of height would be observed, but, instead of the cool air above the forest, there would be a body of heated air rising from barren rocks and slopes, the whole effect of which naturally would be to prevent the cooling, and so to discourage precipitation.

This extreme case gives the argument as to the effect of mountain forests in causing rain. Many observations, some favorable, some unfavorable, and some neutral, to this theory, have been taken all over the world; but the best prevailing opinion of the men who have studied the matter most carefully seems to be that an effect of the forest on rainfall does exist, and that it increases rapidly with the altitude at which the forest grows. However that may be, the influence of the forest in causing rain, whatever it may be, is a matter of comparatively small importance compared with its influence upon the distribution of water after it reaches the surface.

Colonel Chittenden has made an unfortunate choice in comparing the floods of March 17th to 26th, 1907, in Puta Creek and the American River, California. His figures of precipitation for the American water-shed on the east are approximately a correct average of the various gauging stations of the water-shed. But his average precipitation of 22.7 in. for the water-shed of Puta Creek was taken apparently from only two stations, both on the extreme summit of the Coast Range. One station is not on the water-shed of Puta Creek at all, but across the main divide of the Coast Range on the west or rainy side, and the other is just inside the water-shed, but at its highest point. The larger part of the water-shed which lies below is wholly neglected. Fig. 16 is a diagram of these two water-sheds.

Those who are familiar with California understand that the rain clouds from the sea come to the crest of the Coast Range with a con-

Mr. Pinchot.

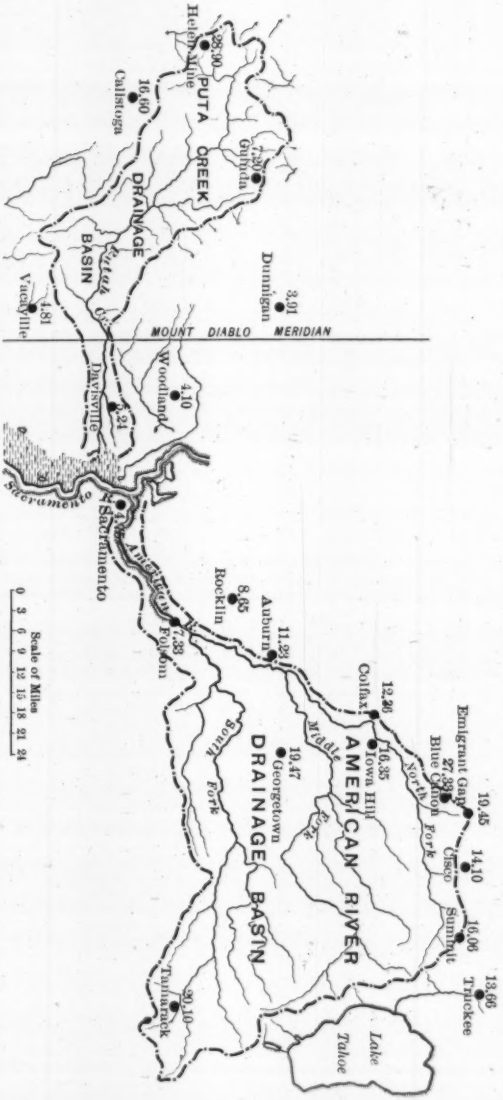


FIG. 16.

Mr. Pinchot. siderable burden of water vapor, and drop it rapidly before and after reaching the crest; as the clouds pass eastward over the Sacramento Valley, the rainfall diminishes with great rapidity.

The other rainfall stations on Puta Creek water-shed or in its neighborhood have been given their due weight, and the results have been worked out in two ways. One is by simply taking the arithmetical average of the stations, from which we get the following results: Puta Creek, instead of having 22.7 in. of rainfall, has 9.44 in.; while the American River has 14.6 in., as given by the author. Calculated in this way, it appears that, although the rainfall on the timbered American River water-shed—and a very much steeper water-shed—exceeded that on the Puta Creek water-shed by 55%, the run-off exceeded that of the Puta Creek water-shed by only 23 per cent.

Calculating by isohyetal lines, we get, instead of 22.7 in. on the Puta Creek water-shed, 10.89 in., with the same result, or 14.69 instead of 14.60 in., for the American River water-shed. From these figures, the rainfall on the American River water-shed exceeded that on Puta Creek water-shed by 53.3%, while the run-off exceeded it by only 23 per cent.

Colonel Chittenden says: "If the forest theory be true, these smooth western slopes should send down a greater flow for the same precipitation than the eastern slope. This is exactly what did happen. When the facts are correctly stated, the forest theory is absolutely sustained.

Passing to the question of flood height and flood frequency, it is perhaps unnecessary to insist that flood height is not the critical factor. As far as the influence of the forest is concerned, flood frequency and duration and the frequency and duration of low waters are the essential considerations.

The statement is made that "the constantly reiterated statement that floods are increasing in frequency and intensity, as compared with former times, has nothing to support it."

There are no long-time figures of stream flow in the United States; but, taking the rivers of which we have definite measures, dividing the time for those figures in two equal parts, and ascertaining for those parts the frequency of floods, the number of days of floods, and the number of days of low water, it is found, in by far the majority of cases, that floods are increasing in frequency, and low waters likewise. In other words, such records as there are for streams with mountain water-sheds, where heavy cutting has been going on, directly support the view that the forest has influence on stream flow.

Figures covering from 15 to 34 years for those streams whose water-sheds lie in the Appalachian Mountains and which have been heavily cut over within the period of measurement, refute the claim that there has been no change in flow during that time. In the report of the

hearing on House Resolution 208, before the Committee on the Judiciary, 60th Congress, 1st Session, it is shown that the Ohio, Cumberland, Wateree, Congaree, Savannah, and Alabama Rivers, disclose a marked increase of floods and flood duration. A more recent examination of the records of flow for the Allegheny, Monongahela, Muskingum, and Potomac Rivers shows precisely the same trend. These streams do not show general increases in the extreme height of floods, but rather a marked tendency of the waters to rush away in many sudden violent floods of short duration, which is to be expected in the case of barren slopes. Most streams of which we have records show a longer low-water period now than formerly, though the tendency is not so marked as the tendency toward increased floods. Where such a tendency is not in evidence, it may possibly be due to the geological formation of the water-shed, or to the filling of the stream channels, so that the general water level is raised. Mr. Pinchot.

In contradistinction to these streams, which have mountainous or hilly water-sheds, the Red River, whose upper basin is entirely in the plains and in a region which has largely been brought under the plow in the last 15 years, shows both diminished floods and greatly improved low-water conditions during the past 16 years. This proves the case over again, only from another point of view. Surface conditions over a water-shed clearly have great influence on the flow of the stream which drains it.

Fundamental errors appear to underlie the author's discussion of influence of forests on snow-melting. The first is that the ground does not take up the water from the first melting of snow. The author says: "The water from the first melting of the snow blanket does not sink into the ground, but into itself. * * * The author has seen an 8-ft. covering of snow dwindle to 2 ft., with the ground beneath it still comparatively dry." Does not evaporation and rapid drainage into the ground account for this? In a forest, especially in a mountain forest, the snow usually falls on unfrozen ground, and the natural warmth of the ground hastens the melting of the snow at the bottom. Whatever free water appears soaks at once into the earth.

It is true that, because the sun is excluded in a dense forest, melting begins later than in the open, and Colonel Chittenden correctly states a universally known fact when he says that, "even after the ground in the open is entirely bare, except under the drifts, the forest areas may still be covered with an unbroken layer of snow." Why? Simply because it is colder in the forest. It is colder when the process of melting begins, it is colder until the snow is gone in the open. The forest consequently acts in exactly the same way as the gulch on the north mountain exposure. It catches the average amount, or in some cases more than the average amount, of snow, and holds it till the melting time in the open is past. If the melting went on as fast in the

Mr. Pinchot. forest as it does in the open, the discharge of water would be greater, considering the whole water-shed, and floods would thereby be intensified.

The only condition under which the melting, for like conditions, is anything like as fast as in the open is during a warm rain, such as often accompanies the "chinook" winds in the western part of the United States. When this happens, the effect is the same on the snow-drift in the gulch and on the snow blanket in the forest. It melts at a most rapid rate. Once melted, there is this difference: Water from the snowdrift is at once in the channel ready to swell the floods, while water from the snow blanket is caught up in the layer of leaves and humus overlying a porous soil, and is retarded at every moment in its downhill course. A portion seeps down through the humus into the stream, a large or even larger part goes into the earth and does not reappear for weeks or months.

The assumption that, "of an 18-in. fall (of snow), perhaps 12 in. is on the trees and the rest spread evenly on the ground," is one which will be disputed at once by anyone who has made a habit of frequenting and observing the forests in winter. Such heavy retention of snow is seldom seen elsewhere as may be found in the cedar forests and swamps of the Northeast; yet even there the speaker, in some considerable experience, has never seen a condition which began to approach the proportion of two-thirds of the snow on the branches and one-third on the ground.

The foregoing is but a partial statement of the relations of the forest to snow. Unfortunately, time is lacking to elaborate it.

Turning to the influence of forests in preventing erosion, Colonel Chittenden says that "he has still to see a single example where the mere cutting off of forest trees has led to an extensive erosion of the soil." He further says that "a soil that will sustain a heavy forest growth will immediately put forth, when the forest is cut down (or even burned down), a new growth, generally in part different from the first, but forming an equally effective cover to the soil."

Those who have studied the forests know that the value of young growth, so far as water supply is concerned, is vastly less than that of the old first growth. If Colonel Chittenden had followed the literature of forestry somewhat further, he would have learned that the destruction of the old forest immediately has the effect of dissipating the humus which is the accumulation of tens and sometimes of hundreds of years. He would have learned, further, that the removal of old trees, however effected, reduces the value of the forest floor in promoting the permeability of the soil. There are endless illustrations which might be used, as in the Adirondacks, in Maine, and in California, where the type of growth which follows the destruction of the old forest is far less favorable to absorption than that which has been destroyed.

Colonel Chittenden has been unfortunate in the case of Fig. 2, Plate XL, which, he says, "shows one of the best examples of this class of timbered land; * * * and no large amount of soil erosion has resulted." Mr. Pinchot.

A perfectly flat place is chosen as an example, on which no erosion will be expected; but on the only slope shown in the photograph, the edge of a ditch, erosion is actually taking place.

Similarly, he says:

"In the forest areas of the East, the growth that follows tree-cutting, consisting not only of new trees, but of briars and small brush of every description, accumulates very rapidly, and forms a more effective mat against erosion than the original forest itself, and is equally effective in storing water."

The mistake is a fundamental one, every woodsman knows or should know, and it can be checked by anyone who will take the trouble to compare the quality of the forest floor in the two kinds of forest.

Colonel Chittenden goes on to say: "Certainly, the ground in a forest under culture, with the débris raked up, is more easily eroded than that of a slashing or second-growth area, or even good meadow or pasture."

Where Colonel Chittenden could have gathered the idea that in any cultivated forest whatsoever, and least of all in the United States, it is the habit to rake up the débris, the speaker is unable to say. But it must be said, with regret, that the statement shows so complete and thorough a misunderstanding of the most elementary foundations of forestry as to invalidate at once in the mind of any man acquainted with the forest, the author's observations or conclusions on all matters relating to the practical management of the forest, or its results.

It is unnecessary to dwell on the statement that it is not forest destruction, but agriculture, which has the effect of causing soil erosion. Whether one destroys the forest to cultivate the soil, or cultivates the soil after the forest is destroyed, makes no difference. In either case, the forest is gone, and its cover has been removed. But the effect of any good cultivation is directly the opposite to Colonel Chittenden's contention, as is shown in the case of the Red River.

The author suggests that we cease devoting the mountain slopes to forests, and take up their cultivation on the lowlands. The failure to conceive the elementary principle in all forestry and in all use of the land, that each part of the soil must be put to the use in which it will contribute most to the National welfare, makes this phase of the question peculiarly difficult to discuss.

As well might it be said that it would be an excellent thing to devote the west side of Fifth Avenue to the growth of lima beans, because their transportation from that place to the consumer in New York City would be so much more convenient and so much cheaper than if they were grown on Long Island. But the west side of Fifth

Mr. Pinchot. Avenue has a greater value for another purpose; and the soil on which Colonel Chittenden recommends that trees shall be grown has a vastly greater value for agriculture than it could ever have for forestry.

The suggestion that trees be planted for the supply of the next thirty or forty years, instead of protecting and guarding the present forests, is the revamping of an idea which was prevalent in the earlier stages of forest agitation in this country. Those who have given attention to the matter have come to see that forest plantations can never take the place of protection of the natural forest and of its natural reproduction.

When Colonel Chittenden objects to the use of the term wasted in speaking of timber lands which pass into the hands of private lumber companies, he fails to remember this vitally important fact, which is another of the fundamental conceptions of forestry, namely, that, when the Government cuts timber from the National Forests, it does so with the distinct and avowed purpose that the land shall go on producing timber. When a great lumber company cuts timber, it proceeds, almost without exception, with the idea that the land shall cease to produce timber. In other words, if the great lumber companies are not wasting timber, because the timber comes into the market, they are wasting forests, which is the essential thing. Less than 1% of the privately owned forests in the United States are being conservatively handled.

A word in summing up: If the speaker's points are well taken and have been made plain, Colonel Chittenden's fundamental conception as to the forest floor and its influence is mistaken. His idea that records in the United States do not show an increase in the frequency of floods and low waters is mistaken. His idea that the critical point to be considered is flood heights, and not flood frequencies, is mistaken. And his conception of forestry, of the functions and management of the forest, beyond its relations to water supply, is so fundamentally mistaken that the speaker might discuss it at far greater length without exhausting the mistakes.

Mr. Chittenden. H. M. CHITTENDEN, M. AM. SOC. C. E. (by letter).—Owing to the wide range which this discussion has taken, it will manifestly be impossible to review it in detail without making the closing argument much longer than the original paper. The most that the writer will attempt will be to go over his seven fundamental forestry propositions, noting how each has fared, and then consider a few of the more important features of the several contributions.

PROPOSITION 1.

"The bed of humus and débris that develops under forest cover retains precipitation during the summer season, or moderately dry

periods at any time of the year, more effectively than do the soil and crops of deforested areas similarly situated. It acts as a reservoir, moderating the run-off from showers and mitigating the severity of freshets, and promotes uniformity of flow at such periods." Mr. Chittenden.

From the further study which the writer has made since the appearance of the paper, and from the various arguments that have been presented by those discussing it, he is more than ever convinced that the above statement errs on the side of liberality to the conventional forestry theory. So accustomed have we become to the idea that the forest bed possesses a vastly greater absorptive capacity for rain water than does the soil in the open country that we rarely stop to verify these impressions by reference to the facts. Plowing and tilling are great agencies in promoting the porosity and absorptive power of the upper layer of the soil. Quite as important is the constant putting forth of plant roots and their annual or periodic decay as crops are harvested or changed. To a great extent do these processes of cultivation open up interstices in the soil that did not exist before, and thus increase its absorptive capacity. Mr. Pinchot has cited an example of this in the cultivation of treeless tracts in the Red River Valley. There may also be cited the example of the Minnesota River watershed and that of Devil's Lake, in North Dakota, where a portion of the water which once flowed rapidly away into the streams is now absorbed in the soil and either given out in the growing crops or conveyed to the streams later through underground seepage.

In the forest, on the other hand, the soil is not soft, as we are commonly led to suppose, unless it be in wet or swampy situations. Under the thin covering of deciduous trees, particularly in the hilly districts of New England and the Middle States, the soil is clean and sharp, unmixed with mould, hard and firm. The writer has verified this fact hundreds of times in actual work. In the evergreen forests of the Rocky Mountains the thin covering of needles has almost no retentive capacity. The ground is often distinctly visible and the shoes of horses passing over it cut into the clean dirt. In the figures shown on Plate XXXVII the forest soil has nothing like the retentive capacity of the soil shown in the open country picture. In the one case it is hard and compact, the covering very thin; in the other, mountain grasses and other plants are growing, the soil is loose and much worked up by burrowing animals, and yields readily to pressure. As between these two typical areas, the open country soil, although never cultivated, has the greater absorptive or retentive capacity.

Particular stress is here laid upon this fact of the naturally compact condition of a forest soil, because of the prevalent opinion to the contrary. Mr. Leighton says that the forest mulch keeps the ground "in a condition that is always equivalent to that of a newly plowed field. No one who has ever scratched away the mulch cover in a

Mr. Chittenden.

forest can deny this." The writer has personally supervised, or has otherwise observed, this scratching away on many hundreds of acres of ground in widely differing classes of forest, and he does deny it most emphatically. Once the rubbish is cleared away, a plow is just as necessary for loosening the soil as in the open country—more so than in land under active cultivation. So far as a rational comparison can be made, taking the country over, the writer would say that, in point of absorptive power, cultivated land ranks first, forest soil second, and old, well-trodden pasture or unbroken prairie soil third.

Theorists expatiate upon the effects of tree roots in opening up the soil and rocks and keeping them porous,* often specifying both soil and rock in the same connection, as if the action of roots upon the two were not exactly opposite. A spike driven into the ground compacts it; into a rock, splits it. The roots of trees do not hang loose in the ground, like a sword in its scabbard. The bond is exceedingly close, and is so developed by the very necessity of keeping the tree from falling.

One feature of the forest soil which restricts its absorptive power is the presence of the trees themselves, and this effect increases in proportion to the density of the timber. An acre of typical Washington forest recently measured showed that 4.3% of the area at ground level was covered by the solid wood of trees of more than 10 in. in diameter. If the trees of smaller growth had been included, the covering would doubtless have amounted to 5 per cent. But this represents only a minor part of the area actually excluded from absorption of rainfall. The large roots of trees spread very rapidly from the surface of the ground down. The earth around these roots and beneath the stump becomes densely packed through the weight of the tree and the stress produced by the wind, which develops a tight bond between roots and earth and ensures the stability of the tree. Those who have had experience in grubbing out stumps realize how close this bond is. It is a matter of common observation that the stumps of trees up-turned by the wind carry with them the solid mass of earth among the roots, and that this is so compact and hard that it often resists for years the action of the elements. This compacted soil is almost as impervious to water as the puddle wall of an earthen dam. Its area is from two to four times the stump area at ground level, and it is a fair assumption that in forests of average density 10% of the soil is thereby rendered not available for absorbing rain water. In very dense forests of large trees this percentage is undoubtedly greater. If these covered areas, of which one never thinks in looking at a forest, were spread out in the form of a concrete pavement they would make an impression. They evidently amount to as much as the ground covering

* "The deep penetrating roots also open passages through which water readily passes into the great reservoir of ground water." Pinchot.

in country towns of 10 000 to 20 000 inhabitants, and are as completely excluded from absorptive activity as is the ground under a city pavement. Mr. Chittenden.

On the whole, it may be considered entirely probable that, acre for acre of ground otherwise similarly conditioned, the cleared land, particularly if under cultivation, will hold and transmit to the ground below more water than will the average forest. What makes the run-off in the open country more rapid generally than in the forest is drainage (including in that term roads and their ditches, regular drainage trenches, tiling, furrows of cultivated fields, etc.), and the roofs and pavements of towns; and it is due to these features, mainly, that the writer's first proposition has a limited application. Omit these features, and the reverse would more than likely be true.

The criticism, by Messrs. Swain, Pinchot, and Leighton, of the writer's "ideal illustration" in the beginning of the paper, because of his use of the words "practically impervious" is, to say the least, captious, and comes with particularly bad grace from Mr. Pinchot who himself has made public use of identically the same kind of illustration. Surely his "photograph of a denuded hillside" from which water sprinkled thereon "disappeared instantly" was practically impervious. In fact, one can rarely make a model which will represent natural conditions accurately, and the best that can ordinarily be done is to take an ideal case, and then note its departure from such conditions. This is what the writer did. No sooner had he stated his illustration than he hastened to explain that it was "never fully exemplified in the cleared land and the forest;" and that there was always an absorptive capacity in soil without any covering; but, that the principle of the illustration applied perfectly, viz., that there were times when the greater retentive capacity of the forest was so far exhausted that it was powerless to act further, and there were other times when it was great enough to absorb all the precipitation that came to it.

The writer, however, might, with perfect correctness, stand upon the literal application of his illustration, if he chose to do so. He was illustrating the difference in absorptive or retentive capacity of the forest and the open country. It would have been entirely proper to have eliminated those features common to both, such as slope and the capacity of the subjacent soil to take up moisture from above, and thus consider the ground in both cases as impervious. It would simply have been subtracting the same quantity from both members of the equation, and would not have affected in the least the principle involved.

Upon the basis of this distorted construction of the writer's words, extreme conclusions have been drawn. These are perhaps sufficiently indicated by Mr. Leighton's statement that the writer "denies that there is a pervious soil under the forest"; and again that he "denies the existence of ground storage." No word can be found in the entire

Mr. Chittenden.

paper to justify either of these statements. Nothing of the sort was in the writer's mind at all. In another place in his paper, speaking of natural reservoirs, he states that "the ground is the most important of these, absorbing on the average probably one-third of the total rainfall." But in discussing the causes of floods he relegated ground storage to the background, for the excellent reason that it plays a very minor part in such occurrences. The great bulk of the water that makes floods is what some one has well called "fugitive" water—that which escapes into the streams over the surface of the ground. Time is the controlling element in the quantity of water that percolates into the earth. A given soil will permit a given quantity to pass through it in a given time, and if Noah's flood were to pass over the surface this percolation would not be any faster. Moreover, what does soak into the ground may be a long time in returning to the surface through springs, and any such portion of a storm plays almost no part in the flood which the storm produces. Whatever part ground-water plays in a great flood (and it is always a minor part) it is generally from precipitation long prior to that which produced the flood, and it cannot therefore be well considered when tracing the relation between a given storm and the resulting flood.

Another point in which some of the writer's critics have found a stumbling block is this: that even though the forest bed be filled to saturation, still the mechanical obstructions to run-off, the crooked and indirect channels, would retard flow more than in the open. But in all the writer's reasoning upon this subject, the superior "retentive capacity" of the forest as compared with that of the open country has included all these retarding causes in the one that are in excess of those of the other; and whenever he has spoken of the forest bed being saturated he has meant that whatever difference may have existed at the beginning of a storm has been obliterated so that the water reaches the streams as rapidly from one class of surface as the other, provided they are otherwise similarly conditioned.

Mr. Leighton makes the following remark in regard to the forest bed: "The common understanding is that the forest mulch is not the storage agent in any except a merely nominal sense." It seems impossible that Mr. Leighton can mean this literally, as otherwise he would sacrifice the position of both himself and Mr. Pinchot, that the forest bed does hold the water of precipitation and give it an opportunity to soak into the ground. Indeed, Mr. Leighton not only contradicts the universally accepted view of forestry advocates, but even his own opinion, as expressed on former occasions. On page 7 of Forest Circular 143, issued November 7th, 1908, is the following from himself and Mr. Horton:

"The Southern Appalachian forests act as a great storage reservoir, and this is done largely through the medium of its humus, the litter

Mr. Chittenden.

of decomposing vegetable matter which forms the forest floor * * * [citation of foreign authorities] * * The function of the forest and of the humus beneath as a storage reservoir is of high importance."

To the same end is the following, from the report of the Secretary of Agriculture, on the Southern Appalachian and White Mountain Watersheds, submitted to Congress December 11th, 1907 (pp. 16-17):

"There is but one natural factor which tends to equalize the flow of the Southern Appalachian streams—the forest. In one continuous mantle, covering ridges, slopes, and coves, it has for untold ages been nature's sole reliance for the proper distribution of rainfall. If storm and deluge came, the downpour fell upon a foot-deep layer of humus, which readily received many times its own weight of water before it allowed any to escape. When filled, it passed on the excess to a soil made porous by myriads of penetrating roots and countless tons of vegetable mold. If drought came, it found the humus and soil filled as a reservoir with water for the steady supply of springs and streams through weeks or months of rainless weather. * * * It was as efficient as would have been a system of lakes. It had power to hold back the water on a steep mountain side almost as though the ground were level."

Read this twice, for it is not only an authoritative announcement that the humus is a reservoir, but it shows that the free play of the imagination has its place even in the most serious public document.

Of course there can be no dispute over the fact that the forest bed, wherever it exists, has a storage capacity, and why Mr. Leighton now says it has not, is a mystery. If he had said that such capacity is greatly over-rated in the popular estimation, he would have been entirely correct, but that it does exist to some extent is not to be questioned, and in certain situations it is quite large. The point of essential importance is that it gives up that storage along lines of least resistance, whether those be by percolation into the ground, by run-off from its surface, or by evaporation into the air. In proportion as the soil itself is porous and the surface slope small, the quantity absorbed into the soil will be greater. And, conversely, as the soil is compact and impervious and the slope steep, the quantity that runs off will be increased. In times of prolonged drought, it may absorb the whole of such fugitive showers as come along, and give them up in evaporation. But it must be carefully borne in mind that in any storm capable of producing a flood, this storage capacity becomes completely exhausted before the storm has progressed far, and thereafter it has no appreciable power to modify the flood. It would probably be a liberal estimate to say that, in our eastern deciduous forests, ½ in. of rain in a continuous shower would exhaust the storage capacity of a fairly dried-out forest bed; ¼ in. in the Rocky Mountain forests, and from 1 to 2 in. in those of the Pacific Coast.*

* This subject should not be confounded with that of the storage capacity of the ground itself below the immediate surface. This is exceedingly variable, depending upon its geologic structure.

Mr. Chittenden.

PROPOSITION 2.

"The above action fails altogether in periods of prolonged and heavy precipitation, which alone produce great general floods. At such times the forest bed becomes thoroughly saturated, and water falling upon it flows off as readily as from the bare soil. Moreover, the forest storage, not being under control, flows out in swollen streams, and may, and often does, bring the accumulated waters of a series of storms in one part of the water-shed upon those of another which may occur several days later; so that, not only does the forest at such times exert no restraining effect upon floods, but, by virtue of its uncontrolled reservoir action, may actually intensify them."

The broad truth contained in this proposition—that floods have not increased with the settlement of the country—is accepted by all participating in this discussion. *Engineering News,* in its criticism of the paper, says:

"We believe that most engineers who give careful study to the question will find themselves forced to accept fully Colonel Chittenden's most important conclusion given under (2) above, viz.: That forests do not prevent floods." And again—"With his main conclusion—that forests have little influence on stream flow compared with what is generally believed—we have already expressed our accord."

Conservation (formerly *Forestry and Irrigation*), the pages of which have always overflowed with the doctrine that forests do prevent, or at least diminish, floods, refers editorially* to "the well-known fact that flood heights do not sensibly increase with deforestation." How many of the readers of this excellent magazine have ever gathered any such impression from its pages heretofore? And finally, Mr. Leighton says that "no well-informed person now believes that flood heights increase with deforestation." The word "now" is significant. The statement itself may be correct; it certainly should be; but it is the very reverse of the teaching so vigorously put forth during the past two years in the interests of forestry.† And some "well-informed persons" apparently cling to the old theory still, if one may judge from the astounding statement by Dr. McGee in the December issue of *Conservation,* that "In a state of nature * * * most streams flow fairly clear and in fairly uniform volume throughout the year."

* November, 1908.

† Mr. Leighton, of course, will be willing that the writer should cite his testimony before the Committee of Agriculture, January 30th, 1908, wherein he not only held that floods are now higher and of longer duration than they used to be, but explained why this must necessarily be so. His remarks are an excellent example of what one can prove if he only makes the right assumptions. Answering a question by Mr. Hawley, Mr. Leighton said in part, comparing the past and present:

"You cannot push through a channel more than a certain amount of water at a certain stage. In the former conditions we will assume that half of the water was taken into the ground and half ran off directly. That half that ran off created a high flood and at the same time it was of shorter duration because the water was not there to continue it. Now, we will assume that it all runs off, but it has got to go through the same channel, between the same banks, and therefore it cannot get through so quickly, and therefore the flood will be higher and at the same time longer continued.

It may be added that Mr. Hawley was so unreasonable as to suggest that "The floods at the time of George Washington spread all over that country."

Mr. Chittenden.

In short, it is true, as every one knows, that the almost universal belief among our people to-day, developed in large part through the agency of supposedly well-informed persons, is that forests do diminish flood heights, and the statement that they do not, comes to most people as a distinct surprise, and their first impulse is emphatically to dispute it.

The position now taken in this matter by Messrs. Swain, Pinchot, and Leighton* involves a complete change of base, so far as the writer's study of current literature, both official and non-official, upon this subject goes. Extreme high waters, it is now held, are not the important matter at all, but the average high waters of a period of years; and for this purpose a period of ten years has been found by the Geological Survey to be long enough. It is difficult to understand just what this means. Mr. Leighton says that by his method the floods are "smoothed out and compensated and afford a less involved idea"; and that "extreme conditions are mere sports, due to unusual occurrences, and it is as illogical to consider them as representative of general tendencies, as it would be to accept the physiological and anatomical freaks in a museum as representative of the human race." The same rule applies also to low waters.

This is very ingenious, and may be entirely satisfactory to Mr. Leighton, but the writer would like to ask him if the idea would ever have found birth had river records been different than they are in the matter of high floods. Does any one doubt that, if the figures in Table 1 of the paper had shown a progressive increase of flood heights with the progress of deforestation, they would have been blazoned from one end of the country to the other as evidence of the baneful effects of deforestation? Now that they show no such tendency, but the reverse, if anything, this feature is pronounced to be quite a subordinate matter, and the main point is said to be the frequency of floods of ordinary height. It is not the great floods that come occasionally, but the lesser floods that come often, that should be considered as of first importance. Mr. Leighton takes periods of years, obtains the means of the floods, smooths or flattens out the irregularities, pronounces these results to be the real criteria, and, by comparing similar periods in states of progressive deforestation, arrives at the conclusion that these smoothed-out results increase as the forests disappear. The great floods which have always come, no matter what the state of the forests, he curtly dismisses as "sports" or "freaks," not subject to intelligent rule and not to be considered as affecting the merits of the question.

Accepting Mr. Leighton's tables as entirely correct (the writer has had no time to verify them) and accepting for the moment the correctness of his conclusion, that the results shown are due to deforesta-

* The writer frequently uses these three names conjointly because their discussions run so closely parallel as to amount practically to identical, or at least supplementary, statements.

Mr. Chittenden.

tion, let the practical aspect of the matter be examined. Will engineers of the country admit that, in the problems of high and low water on our navigable rivers, the extremes are of minor importance, and the average, smoothed-out, floods are the controlling factor? Let us suppose that Mr. Leighton is presenting his views to a committee of land holders in the Lower Mississippi Valley, who want his advice as to the best method of protecting their lands from overflow. Mr. Leighton compares his two smoothed-out periods and shows that if the forestry conditions of the first period can be restored there will be a certain lowering of average flood heights and a diminution of their frequency. If his arguments have any meaning, it must be that if local flood relief measures which will meet these average conditions be supplemented by forest development which will make the conditions permanent, the problem can be satisfactorily solved.

The plan appears simple, but now some one in the committee who has looked up the records inquires if the very highest floods that the river has ever seen did not occur before the forests were cut off at all, and if those high floods were not on the whole as frequent then as they have been in recent years. Mr. Leighton admits that such is the case, but explains, with ill-concealed contempt, that such occurrences are quite out of the regular order of things, and can be considered only as "sports," "freaks" of Nature, which "it is as illogical to consider * * * as representative of general tendencies, as it would be to accept the physiological and anatomical freaks in a museum as representative of the human race." Silenced for a moment by the stunning effect of this reply, the questioner presently ventures to ask what is going to happen to the levees and the property behind them when these freaks do come. This is a poser to Mr. Leighton, and while he is hunting up a satisfactory reply another member of the committee asks how long it will take to reforest the water-shed so as to produce the results that are promised. He is informed that it can be scarcely less than from 50 to 75 years. What will happen in the meantime? Again Mr. Leighton hunts for an answer. What will the reforestation cost? Unknown, but certainly many millions of dollars. Is it a sure thing that agricultural land enough can be given up to provide the necessary forests? In other words, is the proposed reforestation a possibility? That is a point not yet determined, but very doubtful.

By this time those who have listened to the conversation have made up their minds, and they suggest to Mr. Leighton that if he will take the money necessary for reforestation, add it to the funds for local works, get busy and strengthen the levees so that they will keep out the "sports," they will not ask anything of him on account of the "smoothed-out" floods. If the great floods are taken care of, they will not worry much about the smaller ones.

In like manner we may imagine a similar conference with the navigation interests of the Ohio and Mississippi. Is there any doubt that,

in spite of all his tables and plausible arguments, the upshot would be that, if the "sports" or "freaks" (the extreme low waters) are taken care of, navigation will accept the inconveniences that may come from any possible increase in frequency of lesser low waters? Mr. Chittenden.

At the risk of repetition, the writer will notice also Professor Swain's remarks in this connection. He says: "A few great, but not extreme, floods may do more damage than one extreme flood, and may necessitate more expenditure for dredging and other purposes." Professor Swain is a teacher in one of the leading technical schools of the world. Undoubtedly, he inculcates the habit of clear statement and the avoidance of loose generalities in speech on the part of his pupils. But he has violated the most elementary principles upon this subject in the proposition quoted above. What is an extreme flood, and what a great flood? Has he any clear distinction in his own mind? And are causes that operate to produce an extreme flood any different from those in a great flood? The only possible construction to place upon the above statement is that forests produce a beneficial effect upon floods up to a certain limit, and after that the reverse effect. Professor Swain can hardly wish to stand sponsor for any such theory as that.

Again, what would be the practical bearing of the theory, if it were true? In carrying out works of flood protection, if the conditions of the extreme flood are met, all others are included; but if only some lesser floods is considered, then the great floods remain uncontrolled. Now it is of course true that a sufficient number of smaller floods may do as much damage as one very great flood; but, as a general rule, the damage wrought by floods increases very rapidly with their height, and if Professor Swain places a wide limit between his extreme and his great floods it is doubtful if all the latter, on any river that may be considered, cause the amount of damage that the former do. But manifestly the subject, as stated by Professor Swain, is altogether too indefinite to base an opinion upon, one way or the other.

Mr. Leighton and Professor Swain will inevitably find, when it comes to a practical application, that they cannot get very far away from the writer's statement that "it is the extreme of flow * * * that controls the cost of river regulation. It is the floods and low waters that measure the cost. Any scheme of control that is not based upon these is worthless."

The writer now withdraws his momentary acceptance of Mr. Leighton's theory, and challenges his statement that his tables prove "beyond controversy the increase in floods due to deforestation." His theory was first given prominent publicity by Dr. W J McGee in a speech before the Ohio Valley Improvement Association, in Louisville, in October, 1908, in which he presented a table, reproduced here as Table 18. The last two columns have been added to show the stages used by Dr. McGee to denote his floods and the danger line stages that are usually considered as defining real floods:

Mr. Chittenden.

TABLE 18.

River.	First and second period of record.	Mean precipitation, in inches.	Number of floods.	Total days.	Average days.	Flood stage considered in feet.	Danger line stage, in feet.
Ohio, at Wheeling, W. Va.	1882–1894 = 13 years.	38.66	46	143	11.00		
	1895–1907 = 13 "	38.08	59	188	14.40	22	36
Monongahela, at Lock No. 4, Pa.	1886–1896 = 11 "	39.76	30	55	5.00		
	1897–1907 = 11 "	39.27	52	100	9.09	20	28
Cumberland, at Burnside, Ky.	1890–1898 = 9 "	46.27	32	89	9.90		
	1899–1907 = 9 "	41.42	43	102	11.33	25	50
Allegheny, at Freeport, Pa	1874–1890 = 17 "	40.13	39	92	5.41		
	1891–1907 = 17 "	35.23	53	131	7.70	16	20
Tennessee, at Chattanooga, Tenn.	1875–1890 = 17 "	52.10	32	164	9.65		
	1891–1907 = 17 "	45.01	33	143	8.41	24	33
Muskingum, at Zanesville, Ohio	1887–1897 = 10 "	36.87	17	73	7.30		
	1898–1907 = 10 "	35.17	41	171	17.10	15	25

Table 18 makes a very good *prima facie* case. The periods considered on the various streams range from 18 to 34 years, divided into two equal portions, and the mean annual precipitation, number of floods, and average duration of floods, for each, are given. In every case the precipitation in the second period is less than in the first, the deficiency ranging from about 1 to about 16 per cent. In every case the number of floods is greater in the second period, the excess ranging from 3% on the Tennessee to 140% on the Muskingum. In every case but one the average duration of the floods is greater in the second period, the excess ranging from about 15% on the Cumberland to 134% on the Muskingum. Presumably deforestation had been in progress in every case, and the inference of cause and effect was irresistible. *Post hoc ergo propter hoc.* It was indeed an alluring bait, and Mr. Leighton and his associates jumped clear out of the water to grab it; but the writer is much mistaken if they found anything more than an ugly hook from which they would now be glad enough to shake themselves free. Mr. Chittenden.

While admitting the correctness of Dr. McGee's and Mr. Leighton's tables, a prudent investigator would still be very wary about admitting the conclusions which they have drawn from them. There are several things quite near the surface that do not look well. One of these is the brevity of the periods considered and the fact that they do not commence until deforestation is already far advanced. Ten-year periods may satisfy Mr. Leighton, but it will generally be considered that a period reaching back to the time when forests were much more prevalent would be better. Another disturbing feature is the fact that almost no change in forest areas has taken place on some of these water-sheds during the period considered. On the Muskingum, where the changes in flood conditions have been most marked, there has been practically no change in the quantity of woodland. On the Connecticut there has been something of an increase. On the Allegheny and Monongahela the changes amounted to practically nothing on the first stream and 11% of the total area on the second, or 5.5% from any point in the first period to the corresponding point in the second. Manifestly, no possible conclusions, either one way or the other, can be based on such insignificant changes as these. The writer has not the data for the changes in the forest areas on the other water-sheds, but assumes that they are greater than on those just considered.

Another suspicious circumstance is the fact that on the Muskingum, where there were no changes to speak of in woodland areas, and where the mean rainfall for the two periods was practically the same, the increase in floods is by far the greatest; while on the Tennessee, where the difference in rainfall and the change in forest areas are much greater, the difference in flood conditions is least.

Still another, and very important, consideration, which has involved

Mr. Chittenden.

our forestry friends in a serious tangle, is the fact that the duration of floods in the second period is in nearly all cases longer than in the first. If there is any truth at all in the forestry theory, the removal of the forests ought to heighten and shorten the floods; but these tables indicate that it lengthens them! In fact, Mr. Pinchot states that certain rivers in the South, as a result of deforestation, "disclose a marked increase of floods and flood duration"; though, immediately after, in the same paragraph, he returns to the conventional theory that deforestation leads to "sudden, violent floods of short duration."

Discrepancies and contradictions like the foregoing would, as already stated, lead a prudent investigator to pause and inquire. He could not help seeing that there must be some other explanation. Might it not be in the distribution of the rainfall? and might not his very method of toning down and smoothing out the records mask the particular fact that it was necessary for him to know? Such indeed is precisely what has happened. Although the labor of searching out these individual floods and the attendant rainfall was so great that the writer had no time to undertake it, he has fortunately seen a most careful recent study covering a portion of the streams embraced in Mr. Leighton's tables and worked out on truly rational lines. This consists of three tables (Tables 19, 20, and 21) showing rainfall and freshets by months for periods of twenty years for the Ohio at Pittsburg, the Allegheny at Freeport, and the Monongahela at Lock No. 4. These tables were prepared in the United States Engineer Office at Pittsburg, and, at the request of the writer, their use in this connection is permitted. They constitute the most comprehensive study of this question, on so extensive a scale, that has come to the writer's notice Particular attention is invited to them, for they afford a complete explanation of the many discrepancies above pointed out in the study by annual means. The following extract is from the notes accompanying these tables:

"These monthly comparisons are obviously more significant than annual ones, and in general they explain the apparent discrepancies shown by the latter. On the other hand the monthly records also exhibit some discrepancies that can be readily explained by a more detailed examination of such months. In each case they cover a period of twenty years and are summarized for the first and second ten-years. They all give similar results, showing a greater number of freshets for the second period even with a less rainfall. These accordant results are somewhat disturbed, however, when we observe the annual totals. Here we notice but little consistency in the relation between rainfall and number of freshets. On the other hand, this lack of consistency usually finds a ready explanation in the distribution of the rainfall among the different months, and moreover the greater frequency of freshets in the second period is at once seen to result from the very marked increase in rainfall for this period during the month of March, which is one of the greatest flood-producing months. Great

Mr. Chittenden.

TABLE 19—RAINFALL ON THE OHIO RIVER WATER-SHED ABOVE PITTSBURG, PA.

Monthly averages, in inches, from nine stations. Small figures give number of freshets at Pittsburg, 15-ft. stage.

Year.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual.
1889	2.81	2.03_1	1.91	4.50_1	4.08	5.19_1	5.51	2.64	3.64	3.13	5.31	3.41	42.99_3
1890	4.79_2	5.13_2	4.93_2	4.89_2	7.52_2	4.02	2.96	6.09	5.86_1	6.46_2	2.36	4.16	59.18_{13}
1	3.20_2	6.25_3	4.12	3.03_1	3.11	5.54	7.30	4.72	2.56	2.50	3.70	4.20_1	50.30_7
2	3.36_1	2.87	3.14_1	3.40	5.85	4.85_1	4.04	2.92	2.39	1.09	3.65	2.39	39.95_5
3	2.61	5.97_4	1.79_1	5.48_1	5.15_1	4.19	3.61	3.18	2.00	3.65	2.18	3.49	43.29_7
4	2.90	3.30_1	2.18	3.84	6.21_1	2.46	2.35	1.27	5.01	2.50	2.60	4.33	38.95_2
1895	4.09_2	1.27	2.81_1	3.40_2	2.14	3.24	3.68	3.17	1.85	0.95	3.24	3.02	32.86_5
6	1.61	3.09	3.78_1	2.39	3.38	5.03	10.04_2	3.18_1	4.89	2.86	3.06	1.82	45.13_4
7	2.23	4.04_1	4.03_1	4.01	3.51	3.40	5.64	2.96	1.96	0.31	6.10	4.11	42.30_2
8	5.54_2	2.13	6.22_2	2.53	4.37	3.73	3.01	6.75	2.23	4.61_1	3.22_1	2.64_2	46.98_6
9	3.54_2	3.33_1	5.28_2	2.24	5.28_1	4.04	4.78	2.76	3.95	1.22	2.91	3.62	42.95_6
1900	2.65_1	3.89_1	3.44_2	1.42	2.15	4.69	5.15	2.82	1.36	2.73	5.08_1	1.99	37.37_5
1	2.64	1.16	4.09_2	6.50_2	5.40_1	4.30	3.58	5.30	3.24	0.69	3.02	4.94_2	44.86_7
2	2.69_1	2.05	3.92_3	3.72_1	3.21	5.28	6.38_2	2.15	2.65	3.80	1.90	5.73_2	43.48_9
3	3.52_2	4.42_2	4.47_3	3.43	2.96	5.70	4.79	4.55	1.72	3.19	2.91	2.18	43.84_7
4	3.19_1	2.91_1	5.48_2	4.09_1	3.84	3.76	4.66	3.08	2.18	1.92	0.61	3.09	38.80_6
1905	3.36	2.13	4.52_2	3.32	3.66	5.91	6.87	4.19	2.91	4.65	3.16	3.76_2	48.44_4
6	3.30_1	1.31	4.56_1	3.31_1	2.99	4.61	4.27	5.43	3.18	3.30	1.71	4.97_2	42.84_5
7	7.02_2	2.09	6.06_2	3.19	3.66	4.82	5.85	3.46	4.53	2.95	2.91	3.45	49.99_4
8	2.95_1	4.49_1	6.66_4	4.48	6.59_2	3.12	4.75	2.36	1.00	0.60	0.97	3.22	41.19_8
First ten years.	33.14_9	36.08_{12}	34.91_9	37.47_7	45.32_4	41.65_2	48.14_2	36.88_1	32.39_1	28.06_3	35.42_1	33.57_3	44.193_{54}
Second ten years.	34.76_{11}	27.78_8	48.48_{26}	35.70_5	39.74_4	46.23_9	41.08_2	36.10_0	26.72_0	25.05_0	25.18_1	36.95_8	43.376_{63}

TABLE 20.—MEANS OF MONTHLY RAINFALL AT WARREN, CLARION (OR FRANKLIN), JOHNSTOWN AND FREEPORT.

Small figures give number of freshets at Freeport, 16-ft. stage.

ALLEGHENY RIVER.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual.
1889	3.13	2.12	1.97	5.29	4.04	5.66	6.62	3.36	3.99	3.42	4.46	4.08	48.14_0
1890	4.97_1	4.77	4.68	5.00_1	7.70_2	3.41	2.48	6.06	6.62_1	6.28	2.63	3.89	58.49_4
1	2.94	5.86_2	3.96	2.56	1.96	6.00	8.16	3.99	2.45	2.66	3.98	4.14	48.66_2
2	3.61	3.26	3.03_1	2.40	6.80	5.92_2	3.50	2.79	2.71	1.32	3.92	2.24	41.50_3
3	2.98	7.37_2	2.53_1	5.52	5.65_1	4.31	3.44	4.00	2.11	3.55	2.37	4.48_1	48.31_8
4	3.34	3.14	2.05	3.44	7.14_1	2.58	2.02	0.78	6.96	2.72	2.57	3.76	40.50_1
1895	4.30_1	1.34	2.17	3.08_2	2.46	3.66	3.43	3.69	2.86	1.05	3.79	3.21	35.04_3
6	1.31	3.18	3.85_1	2.38	3.14	4.53	7.40	3.66	5.26	2.62	3.11	1.81	42.25_1
7	2.29	2.77	4.48_2	3.67	3.80	3.13	6.48	3.31	2.12	0.35	6.15	3.34	41.89_2
8	5.13_2	2.06_1	5.33_1	2.10	4.74	4.36	3.05	7.07	2.10	5.12	3.69	2.65	47.40_4
9	2.91	3.44	4.94_1	2.43	5.68	3.18	4.25	2.99	3.93	1.53	2.60	4.32	42.30_1
1900	3.09_1	4.07_1	3.16_1	1.36	2.17	4.34	5.74	3.12	1.79	2.75	5.28_1	1.92	38.79_4
1	2.97	1.29	4.37_2	5.79_2	5.48	4.90	3.95	6.98	3.89	0.82	3.50_1	4.04_1	47.98_5
2	2.14	1.82	3.69_2	3.61_1	3.39	5.97	7.60_1	1.96	3.95	3.57	1.56	5.61	44.87_4
3	3.69	4.08_2	4.60_2	3.35	2.59	5.72	4.96	6.10	1.68	3.45	3.18	2.26	45.66_4
4	3.49	3.18_1	6.00_2	4.76_1	4.57	3.65	6.46	3.75	2.49	2.17	0.92	2.80	44.24_6
1905	3.44_1	1.95	4.05_2	3.39	3.36	6.06	8.39	4.14	3.61	4.74	3.39	4.18_1	50.70_4
6	2.75	0.97	4.21_1	2.60_1	2.90	3.97	4.32	6.02	3.34	3.77	1.63	4.44	40.92_2
7	5.98_1	1.55	5.24_2	3.26	3.40	4.67	3.57	2.74	4.99	3.27	2.83	3.48	44.98_3
8	3.24	4.84_1	6.58_4	3.90	6.55	3.35	4.54	2.12	0.87	0.50	1.14	3.37	41.00_5
First ten years.	34.00_4	35.87_5	34.05_6	36.44_3	47.43_4	43.56_2	46.58_0	38.71_0	37.18_1	29.09_0	36.67_0	33.60_1	45.218_{26}
Second ten years.	33.70_4	27.19_5	46.84_{20}	34.45_5	40.09_0	45.81_0	53.78_1	39.92_0	30.54_0	26.57_0	27.03_1	36.42_2	44.134_{36}

Mr. Chitten-den.

Mr. Chittenden.

TABLE 21.—MEANS OF MONTHLY RAINFALL AT WESTON, W. VA., ROWLESBURG, W. VA., AND LOCK NO. 4.

Small figures give number of freshets at Lock No. 4, 20-ft. stage.

MONONGAHELA RIVER.

Year.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual.
1889	2.77	1.85_1	1.68	4.16_1	3.22	4.98_1	4.85	1.72	4.01	3.06	6.83_1	2.64	41.77_4
1890	4.80_1	5.44_3	4.96_1	4.71	8.32	5.26	3.87	6.92	5.38	6.43_2	2.31	4.07	62.47_7
1	3.34_1	6.25_3	4.60	4.24_1	4.41	5.04	6.24	6.09	2.57	2.37	3.82	4.75	53.72_8
2	3.13_1	2.67	3.52	4.44_1	5.55	3.62	3.77	3.47	2.35	1.05	4.05	2.84	40.46_2
3	2.29_1	4.60	1.21	5.31	4.22	4.92	3.67	2.16	1.76	3.82	2.00	2.59	38.55_1
4	2.52	3.54	2.21	4.07	5.64	2.76	3.00	2.19	3.36	2.31	2.81	5.02	39.43
1895	4.16_2	1.29	3.61_1	4.29	1.84	2.65	3.71	1.92	0.99	0.86	2.91	2.86	31.09_3
6	2.12	1.93	3.47_1	1.89	3.30	5.88	13.21_2	2.47	4.03	3.50	2.81	1.92	46.53_3
7	2.03	5.03_1	3.50	3.56	3.11_1	4.21	4.09	3.08	1.65	0.28	6.45	5.28_1	42.27_3
8	6.39_2	2.33	7.47_3	3.31_1	4.02_1	3.01	2.57	6.72_1	2.81	3.96_1	2.81	2.70	48.10_9
9	4.13_1	3.43_1	6.07_2	1.81	5.27	5.24	5.42	2.57	3.84	0.69	3.26	3.24	44.97_4
1900	2.50	3.95	4.00_1	1.49	2.43	5.24	3.91	3.23	0.87	2.77	4.76_1	1.69	36.84_3
1	2.33	1.04	3.77	7.12_2	4.87_1	4.22	3.34	3.88	3.04	0.53	2.84	6.28_2	43.26_5
2	3.78_1	2.33_1	4.30_2	3.76_1	2.88	4.59	6.17	2.58	2.47	4.23	2.71	6.40_2	46.20_7
3	3.37_1	5.82_2	4.85_2	3.88	3.81	6.47	4.55	2.83	2.03	3.13	2.64	2.50	46.88_6
4	3.11_1	2.96	5.35_1	3.86	2.92	3.94	3.67	2.09	2.05	1.64	0.45	3.30	35.34_2
1905	3.53_1	2.59	5.47_2	3.57	4.32	5.22	6.28	4.07	2.44	5.01	3.12	3.80_1	49.42_4
6	5.89_1	1.89	5.19_2	4.49_1	3.25	5.72	4.38	4.56	2.95	3.14	2.06_1	5.77_2	49.29_7
7	7.99_2	2.79_1	6.90_2	3.31	4.50	5.16_1	9.46_1	4.66	4.77	3.18	3.34	3.08	59.74,
8	2.93_1	4.77_1	7.31_3	4.42	7.58_2	3.46	4.10	2.42	1.01	0.78	0.86	3.49	43.13_7
First ten years.	33.55_9	34.93_8	36.23_6	39.98_4	43.63_1	42.33_1	48.98_2	36.74_1	28.91_0	27.64_3	36.80_1	34.67_1	44.439_{37}
Second ten years.	39.56_9	31.57_6	53.21_{17}	37.71_4	41.83_3	49.26_1	51.28_1	32.89_0	25.47_0	25.10_0	26.04_2	40.15_7	45.507_{30}

Mr. Chittenden.

variations will be observed in the rainfall for the same month, as well as from month to month for the same year, though the mean monthly averages do not differ so widely. The comparative absence of freshets in the summer illustrates the influence of temperature. It is clearly not due to less rainfall in that season, since the average precipitation then is greater than during the flood months. * * *

"It will be found by a careful examination of these tables that usually the occurrence of the freshets is sufficiently explained by the monthly rainfall. Now and then discrepancies appear, especially during the flood months, as when a freshet accompanies an unusually small rainfall, or fails to accompany a comparatively large rainfall. In such cases an examination of the hydrograph usually shows that the small rainfall was concentrated in a few days, while the large one was distributed through the month and sometimes accompanied by several freshets that failed to reach the stage under consideration. It is believed that these considerations, making freshets entirely dependent on rainfall and temperature, fully meet the arguments of those who attribute their increase to deforestation."

Several interesting facts are disclosed in these tables. Note that practically the whole excess in number of floods in the second period occurred in the month of March and that it is all accounted for by excess of rainfall for that month. The effect of temperature has been pointed out. This, of course, acts not only through direct evaporation while a storm is going on, but through the greater absorptive capacity of the soil at such seasons, due to its drying out more rapidly when it is not raining, and to the heavy draft for the growing crops and trees. It takes a heavier rain at such times to produce a given result in stream flow than in the cold seasons of the year. Again, after a period of high rainfall, the precipitation for a month may produce a greater flood than the same precipitation after a period of light rainfall, other conditions being the same. A more minute study, going into the details of each storm, would be required to explain all discrepancies; but these monthly records go a great way in that direction and indicate the proper lines along which a study should be developed. The writer regrets that because of lack of time he could not carry this study to other water-sheds, but until it is so applied to every case, any pretense that changed flood conditions on such water-sheds are due to changes in forest areas is entirely without warrant. There is nothing in our existing state of knowledge to indicate that these records may not be completely reversed in the next ten years.

It is submitted that the above exhibit effectually punctures the iridescent bubble which Messrs. Swain, Pinchot, McGee, and Leighton have set afloat in this discussion. Their vaunted criterion of a ten-year period is a pleasing pipe dream and nothing more. Their smoothing-out process is a smothering process. It suppresses the very facts that the engineer most needs to know. It substitutes a sham for the real thing. It is fundamentally unscientific.

Mr. Chittenden.

Both Professor Swain and Mr. Leighton have misunderstood the writer's argument in regard to the effect of forest storage in promoting tributary combination, though each has criticized it from a different point of view. As they have understood it, the writer entirely agrees with both. The sketch illustrations given by Professor Swain are doubtless true for the conditions as he states them, and he could multiply such illustrations indefinitely and find conditions in Nature that would fit them all. The trouble with this method of reasoning is that it proves nothing because it proves everything. Any one who embarks upon this sea of confusion will "find no end, in wandering mazes lost," and will soon throw up his hands in despair. Fully understanding the impossibility of coming at any definite result in this way, the writer did not go into it in his paper, but stood upon the indisputable fact, as shown by the records, that rainfall and floods and low waters are essentially the same now as they were before the forests were cut off.

In like manner, Mr. Leighton's point that any draft upon the storage in the forest bed leaves room for that much more is, of course, entirely correct, and the writer has nowhere said anything to the contrary. What the writer did say in elucidating this subject was:

"When a period of heavy storms occurs, spreading over a great area, continually increasing in intensity, the forests, by retaining some portion of the earlier showers and paying them out afterward, do produce a general high condition of the river which may greatly aggravate a sudden flood from some portion of the water-shed."*

This may be made clear, if there is really any doubt as to its meaning, by comparing it to a similar phenomenon with which all are familiar. Take the case of ground storage, acting through a longer period. After a long wet spell the superficial springs and underground sources become replenished, the small streams swollen, and the trunk stream assumes a high stage. Manifestly, this condition is less favorable for the reception of a heavy flood from any portion of the water-shed than if the river were low. In like manner, to the extent to which it is effective, forest storage operates in the same way. If the writer were to re-write the sentence above quoted, he would omit the word "greatly," because the more he considers it the less weight is he inclined to give to the forest bed as an agency for holding water. In fact, he did indicate this feeling to some extent in a later sentence in which he said:

"It is not contended that this increase is ever very great, but it is contended that forests never diminish great floods and that they probably do increase them somewhat."

* The phrase "some portion of the water-shed" is used because it rarely, if ever, happens that, in a great river like the Ohio, the downpour that brings the crisis of the flood covers all, or even the larger part, of the water-shed.

Mr. Chittenden.

In reviewing the wording of Proposition 2, the writer can see that, taken by itself, it may justify the interpretation of Professor Swain, but not if read in connection with the explanation in the text. It would convey the writer's meaning more clearly if the words "may, and often does, bring the accumulated waters of a series of storms in one part of the water-shed upon those of another which may occur several days later," were changed to read "may, and often does, produce an increase of stage in a river, which may aggravate a later flood coming from some portion of the water-shed."

PROPOSITION 3.

"In periods of extreme summer heat forests operate to diminish the run-off, because they absorb almost completely and give off in evaporation ordinary showers which, in the open country, produce a considerable temporary increase in the streams; and therefore, while small springs and rivulets may dry up more than formerly, this is not true of the larger rivers."

The writer has already called Mr. Leighton to account for misstating his position in regard to ground storage. He nowhere ignores its existence. Neither has he anywhere said what Mr. Le Baron implies he has said, that "if there were no springs, rivulets, or brooks," there would still be rivers. What he did say is: "The difference between the former low-water flow of a spring or rivulet and what it is now is relatively an insignificant quantity." He was dealing with relative, not absolute, quantities. Formerly streams were lower in autumn than in spring; the same is true now. The current theory is that they fall lower now than they once did. The writer simply said that, whatever may be the difference between the former time and now, it cuts very little figure in comparison with the total flow that makes up a river. And he will now add that he is more convinced than ever that the difference itself is very greatly exaggerated in the public mind.

Springs are, of course, an exceedingly important factor in stream flow, possibly more important than the surface run-off. In time of flood the surface run-off is far the greater. In times of low water the spring supply is generally, though not always, the greater. In considering the function of springs in the low-water flow of streams, it is necessary to take into account their origin and character. For this purpose they may be classified as deep and shallow springs—that is, those that come from deep subterranean sources and those that emerge in the near vicinity of their supply. The true spring—the spring of real economic importance—comes from deep and distant sources. Its course before emergence may lie for great distances between impervious strata, where it is entirely cut off from external influences. Springs of this class are generally permanent, respond slowly to precipitation, and vary but little throughout the year. Every country

abounds in them. In 1898 the writer investigated with great care a number of these springs in the vicinity of Huntsville, Ala., and could find no evidence that they are smaller now than formerly, though in one case his evidence extended to the period before the Civil War. Important towns in various parts of the world rely upon such sources of supply. It is these springs that yield the bulk of the low-water flow of streams, so far as this comes from the ground, and it is not likely that their present volume is much less than before the forests were cut off. Mr. Chittenden.

Springs of the other class come from shallow sources, the water reappearing in the near vicinity of where it soaks into the ground. Such springs are very copious in wet weather, and their aggregate volume probably exceeds that of the other class. But they are much less permanent, responding quickly to surface conditions and drying up much more completely than the deeper springs. It is within the knowledge of everyone who has rambled much through the country, either forest or open, that all such springs diminish greatly in dry weather and often disappear altogether. So far as springs have suffered at all from deforestation, it is this class which has suffered most. But it is wholly a mistake to assume that such springs did not generally dry up when forests covered the country; and the actual deficiency since the woods have been cleared away is probably much less than popularly supposed. The writer has observed these springs and the small streams in different kinds of forest, and knows, from experience in the handling and use of such sources of supply, that they are extremely variable with seasons and with precipitation conditions.

At this point it is worth while to consider the evidence relating to this matter of the drying up of springs, wells, and little streams. It is for the most part hearsay evidence only, and of the most unreliable character. While the forest remains around a spring, the latter is ordinarily not closely observed. When the land is cleared, the spring is generally brought into use. In the case of many small springs which the writer has observed, the demand upon them has greatly increased with the development of the country, and their capacity has become deficient. Under such circumstances the user is likely to say that the supply is growing less. In scarcely any case of the flow of a small spring is there a reliable record extending over a considerable time.

In the case of wells of considerable age, the evidence is more definite that the water in them stands lower than it did when they were built; also, that new wells have to be dug deeper than formerly; and this is said to be due to the removal of the forests. Again, "after this, therefore on account of this" is the only reason for connecting the two facts as effect and cause. There is only one thing that we know with cer-

Mr. Chittenden.

tainty in this connection, and that is that water is drawn from wells. In some places great quantities are drawn. Wells are numerous everywhere in the country, very many towns rely upon them for their supply, and the demand for these latter purposes ranges from 50 to 100 gal. per individual daily. The already vast, and rapidly increasing, consumption of water for domestic and industrial purposes comes to a large extent from wells and springs and little streams. The water consumed by locomotives alone in the United States amounts to 1 700 cu. ft. per sec., 40% more than the extreme low-water flow of the Ohio at Wheeling. May not the draft of water for these manifold purposes have more to do with lowering the water-table around wells and the absorption of the flow of springs and little streams than the substitution of cultivated ground for the forest?

In a well in Prospect Park, Brooklyn, a continuous draft of less than $\frac{3}{4}$ cu. ft. per sec. caused the water level to fall nearly 6 ft. in ten years. During this time there was no change in forest cover. In some places this effect of wells has been traced several miles. Is it not altogether likely that if all wells could be closed for a period of, say five years, most of the lowering of water level attributed to forest removal would disappear?

The commonly cited example of defunct mill-powers is another case of defective evidence. Let any one trace the history of an abandoned mill built in the early days on any of our small streams, and search out the actual cause of its abandonment, and the chances are that, in nine cases out of ten, he will find that it was for business, not physical, reasons. In some cases deforestation has ruined sawmills, not by cutting off the water supply, but by cutting off the timber supply. But the great cause of the abandonment of little mill-powers has been the development of steam, by which all the work formerly done by the little mill has been done much more effectively and cheaply. Rightly understood, the old abandoned mill-powers are evidences, not of the diminishing flow of our streams, but of failure in the battle with steam. The improved weapons of water-power—the turbine, the impulse wheel, and electricity—and the growing cost of steam are now turning the tide of conflict the other way.

The evidence of the oldest inhabitant, so often cited, is never reliable. The writer has himself tried the plan of collecting opinions of individuals as to the drying up of springs, etc. There is always a strong affirmative majority, but there is also a minority large enough to upset confidence, particularly when it is found that such minority generally embraces the closest observers. An example may be seen in the recent widely-quoted report of the Pennsylvania Flood Commission, in which a summary was given of replies received to certain questions as to the effect of deforestation upon the flow of the Susquehanna River. In one set of replies there was a large minority that

thought no effect was traceable; in another set of replies this minority was much smaller; but in neither case was the vote by any means unanimous. The drawing of hard-and-fast conclusions upon evidence of this sort is open to the same criticism as was the verdict of a jury who acquitted a man of theft because six witnesses swore that they did not see him commit the theft, and only four that they did see him commit it. The simple fact is that our evidence in all these matters is not clear, and that the tendency has been to ignore or set aside many good and valid explanations of existing phenomena and attribute them to one cause alone—the cutting off of the forests. Mr. Chittenden.

Coming back to his argument, the writer holds that the strong and permanent springs, which form the real sources of our low-water supply, have not changed appreciably with the development of the country; that the superficial springs possibly dry up more than formerly, but that the difference between their former and present condition is much exaggerated; and that in most cases the diminished flow of little streams is due to the increased use of the water more than to the clearing of the land. To offset this diminished flow where it exists there are several influences brought into effect by the settlement of the country. In towns, a portion of the water supply drawn from wells or springs, or stored in reservoirs during high water, finds its way back into the streams as sewage. In some towns cistern storage is sufficient to absorb a large part of the rain that falls on roofs, and a portion of this finds its way back into the streams in low water. But the principal compensating effect is the run-off from summer showers, to which the writer refers in his paper. In the low-water season the difference between the forest and the open country in the matter of restraining run-off is at a maximum. The forest prevents practically all such showers from reaching the streams, whereas the effect of roads, ditches, and pavements in the open country is to deliver some portion into the streams. Every one has witnessed this difference at such seasons, and its effect is at times considerable. Putting all these causes together, it is clearly not a proven fact that the aggregate flow of small streams in the open country during periods of low water is less than it was under forest conditions. It may be more irregular. It may fall lower, but at the same time it may rise higher and the aggregate result may be very doubtful.

Mr. Leighton repeats the old dictum, which is just now enjoying a revived popularity, that a "stream is a stream from its mouth to its source," meaning thereby that no really comprehensive method of dealing with the lower course of a river is possible which does not take into account the extreme head-waters as well. This used to be a favorite doctrine with the writer, and, to a limited extent, is so still; but he has long since learned that the only real resemblance between a great river and any one of its innumerable sources is the fact that both

Mr. Chittenden.

are carrying water on its way from the uplands to the sea; and he believes the truer doctrine is, in the words of Colonel Roberts: "A river is a river, and a creek is a creek." Let any one reflect but a moment upon the many and radical differences between these two classes of streams, and he will see that their practical relationship is often more fanciful than real. Only one feature of difference will be noted here, and that is the reservoir function of the trunk stream. A river is made up of tens of thousands of little tributaries. These are separate sources, often acted upon by separate causes—some experiencing freshets, while others are entirely undisturbed, and all changing in their flow more or less independently of one another. The river knows nothing of these irregularities. The freshet of a remote tributary causes scarcely a ripple on its surface. The river is a reservoir. It is uniform in a sense that little tributaries never are. It responds only to general causes that affect a great number of tributaries alike, and most readers of this paper will have no difficulty in understanding what is meant by uniformity of flow in a river, as distinguished from any one of its numberless sources. It is therefore in the great river, where the infinitely variable elements of its supply are integrated into one definite result which can be observed and measured, that we should go to see whether the flow of our streams is smaller in volume than it used to be. Resorting to this tribunal, we find nothing to justify the popular theory. Whatever may be happening to the springs and wells and little streams, as much water gets into the great rivers in low stages as used to, and apparently more. The low-water flow of the Monongahela at Pittsburg for 1908, about 200 cu. ft. per sec., was certainly as great as in certain other extreme low waters, and if it could be corrected for losses for industrial uses that have come into existence in the past fifty years, its discharge at the height of this extraordinary drought would be found to be materially larger than in the great drought years of 1838 and 1856.

In fact, it is growing evident, as this matter is looked into more carefully, that the forest, in more ways than one, is a voracious consumer of water during periods of drought, and that it is not at all the source of low-water supply that it has been held to be.

Proposition 4.

"The effect of forests upon the run-off resulting from snow-melting is to concentrate it into brief periods and thereby increase the severity of freshets. This results (*a*) from the prevention of the formation of drifts, and (*b*) from the prevention of snow-melting by sun action in the spring, and the retention of the snow blanket until the arrival of hot weather."

As to the soundness of this proposition, the writer is quite content to rest his case upon the judgment of those who will carefully read

his argument, supplemented by the statements of Messrs. Leffingwell, Strong, and Johnston, and even of Colonel Pickett himself. He would also cite the article from *Science* which is included in the Appendix. The proposition has come to many as a surprise, and their first impulse has been to deny it, and this impulse has led to the only efforts of consequence, and these very feeble ones, to controvert the writer's argument. Mr. Chittenden.

Mr. Leighton says that drifts form in forests. Occasionally; but such drifts may generally be accounted for by the topography. A sharp ridge, for instance, by forming an eddy in the air, causes the snow to collect more deeply behind it. Such instances are in direct line with the writer's theory. The only situation where the trees themselves form drifts is on the edge of the timber, where the wind blows into it from the open. In such cases drifts will accumulate for a hundred yards or so under cover, depending on the density of the timber.

But Mr. Leighton is wholly wrong in asserting that but a small part of the snow in the open gathers into drifts. Omitting the very early and very late snows, which are generally wet and accompanied by less wind, the vast bulk of the mountain snows falls under the influence of the wind. This snow is dry and floury, and yields to the slightest breeze. In the open country it is nearly all thrown into drifts of greater or less magnitude.

The writer craves the pardon of the Society for referring so much to his personal experience, but the position taken by certain participants in this discussion, in holding that there is no essential difference between the forest and open in the way in which snow collects on the ground, seems so extraordinary that he is inclined to specify more particularly the sources of his own knowledge. For many years his work brought him frequently in the heavy forest during the worst storms of winter, while in the spring he was almost constantly in the woods in connection with the making of maple sugar, from the very earliest melting until the leaves were out on the trees. This was in a dense, primeval, deciduous forest, and in a country of very heavy snowfall. He states most positively that in such a forest the snow never drifts to any great extent unless there are sharp hills, or openings, or other similar disturbing elements, and that then it does not drift as in the open country. In the region here considered, drifting in the open was the rule everywhere after cold weather really set in, and was a source of great inconvenience to travel wherever there were fences along the roadside. Nothing was more common than to see roads staked out through these drifts, or the highway abandoned altogether, and travel taken to the open fields. No such trouble was ever experienced where roads lay through extensive forests. These open country drifts often lasted until the land around them was dry and dusty and the forest bed well dried out.

So in the mountain forests; there is a long belt of open country,

Mr. Chittenden.

from 5 to 10 miles wide, extending along the northern border of the Yellowstone Park, and constituting the greater portion of the grazing ground for game. A road extends east and west for 50 miles through this section, and 4 miles of it are in a heavy forest. The drifts form so heavily in the open section that in many places it is impossible to maintain travel except by leaving the road and going around the drifts. This trouble is never experienced in the forest.

Fig. 1, Plate XXXVII, accurately depicts the condition of the snow in a dense forest. Someone has hinted that this is a fresh snowfall. A glance at the left of the picture, where the ground at the foot of the trees is entirely bare from sun melting, would have saved the necessity of that suggestion. The writer took this picture himself, and at the date on which it was taken the snow all over this country lay in a solid, nearly uniform blanket, fully 4 ft. thick. Within ten days it was nearly all gone. The two pictures in Plate XXXVII will bear study. They tell the whole story, and the writer can only say, of those who belittle the difference between forest and open country in the matter of snow distribution, that they are not familiar with the subject. Surely Mr. Pinchot has never "entered into the treasures of the snow" in his study of our western water supply, or he would not speak lightly of the great reservoirs formed by the drifts of our mountains. They do more to equalize and prolong the flow of such streams than any other cause, except, possibly, the deep subterranean springs.

Mr. Leighton is also in error in what he says about the melting of snow from underneath. This does not take place to any appreciable extent in the Rocky Mountains. The heavy snows—the real accumulation of winter—come in February and March. Long before this the ground under the thin covering of the earlier snows is frozen solid to a considerable depth. It does not thaw out during the winter enough to cause any appreciable melting of the layer of snow above it. Even such melting as does occur soaks into the snow rather than into the ground, for the snow is the better sponge. The writer has examined this matter too many times to admit of any question upon it. The sub-surface melting is practically a negligible quantity, and the winter's supply of snow, except such as escapes in evaporation, gradually compacts until it reaches a stage of saturation at the time when the genuine warmth of summer arrives.

This condition also prevails, though to a less degree, in the eastern deciduous forest, as confirmed by Messrs. Le Baron and Snow. The difference in temperature between the forest and open country is not great, and while the ground is more protected in the woods than under the thin covering of the open, it is not as well protected as under the open country drifts. But there is one feature of these forests that effectually hinders the assumed soaking into the ground from subsurface melting, and that is the flattened out layer of leaves to which

Mr. Snow has called attention. Anyone who has observed the condition of the forest bed under deciduous trees just after the snow has disappeared will understand this. Those leaves virtually form an oil-cloth separator between the snow and the ground, and whatever melting there may be from beneath is drawn up into the open sponge above rather than through the leaves into the ground beneath. This fact should be borne in mind by those who lay so much stress upon the frozen condition of the ground on our eastern water-sheds when the floods of winter and early spring take place. This condition in the open country is partially, and possibly fully, offset by that of the forest bed above described, particularly when the bed of leaves is itself sealed up by frost. Mr. Chittenden.

The curves (Fig. 1), to which Mr. Leighton refers so slightingly, will stand as a rational expression of a scientific truth which will be fully recognized as this subject comes to be better understood. The time scale has more immediate application to the great central Rocky Mountain region about the sources of the Yellowstone. The vertical scale is, of course, only a most general expression. As shown in the figure, it represents the writer's estimate of an extreme case, like the flood of 1899. In average years the two crests are much closer together. The great saving factors in these mountain floods are difference of altitude and changes of weather. The lower altitudes yield up their waters first, and these are safely carried away before those from the higher altitudes come down. The melting at the same altitudes is often interrupted by a sudden drop in temperature. On more than one occasion has the writer taken measures to patrol the roads in the Yellowstone when conditions seemed to make a flood imminent, but has been spared any trouble by a sudden change of weather which stopped melting, tightened up the little streams and allowed the accumulated waters to run away. This, in fact, is the general rule; but every five or six years a season will come in which warm weather and rains continue for several days without interruption, and it is then that disasters follow.

The writer will note here a common, but very erroneous, impression to the effect that delay of forest melting is a benefit to irrigation. This point has been urged by Colonel Pickett and by the Editor of *Engineering News*. Far from being a benefit, this delay, by concentrating and intensifying the run-off, is a positive injury by the damage it causes to irrigation works. The water comes in such volume that it cannot be used, and all the excess which constitutes the flood is absolutely lost to irrigation. Storage reservoirs alone can save it. Particular attention is invited to the fallacy of popular thought in this matter, because it has a bearing upon the main question here considered.

Professor Swain takes exception to the writer's statement that the

Mr. Chittenden. forests of the Pacific Coast intensify floods, and asks, "Would it not be more correct to say that * * * even in densely forested areas there may be tremendous floods?" No, that would not define the situation, at all. The fact is that we have here, as stated in the paper, "the densest forests in the world, the deepest beds of humus, and the most perfect reservoir effect so long as it is in action." In building a road into the Mount Rainier National Park, the writer found that the clearing away of the débris which covers the soil was in many places the heaviest item of the work. It is often 2 and 3 ft. thick. If there is anything in the forestry theory, we should find it more fully exemplified here than anywhere else. Yet the contrary is the case, and the writer believes it to be strictly a true statement that freshets are more sudden and violent, and caused by smaller rains, than in the cultivated sections of our Eastern States. It was a great surprise to him to learn this fact; but the explanation now seems to him very obvious. The snow and the subsequent warm rains have the effect of bringing two storms together. The forests enhance this effect by distributing the snow so that a vastly greater area is exposed to the melting influences than would otherwise be the case.

To show how strikingly true this is, the records of the flood of November, 1906, on Cedar River are given in Table 22. This is an important stream, though a small one, for it furnishes the water supply for the City of Seattle, and its water-shed is to be thoroughly protected and its records carefully kept. Table 22 gives the record for November 12th to 18th, 1906:

TABLE 22.

Date.	Temperature.	Rainfall.		Discharge of Cedar River.
		Inches.	Cubic feet per second.	
Nov. 12th	50°	1.34	5 027	1 430
" 13th	56°	2.12	7 992	3 028
" 14th	60°	1.15	4 335	7 610
" 15th	55°	2.26	8 483	10 800
" 16th	44°	0.07	254	6 930
" 17th	44°	0.07	254	3 610
" 18th	50°	0.00	0	2 380

The area of the water-shed is 143 sq. miles, and the maximum flow in this flood was therefore about 75 cu. ft. per sec. per sq. mile. The distance to the gauging station from the center of the water-shed is about 12 miles, and it is probable that the run-off, as measured, all originated within the previous 24 hours. Comparing the rainfall of the four days, 12th to 15th, with the run-off for the four days, 13th to 16th, it appears that the run-off exceeded the rainfall by 632 cu. ft. per sec., or about 220 000 000 cu. ft. for the four days. The discharge

CEDAR LAKE, ON CEDAR RIVER WATER-SHED.

of the river just before the storm began was about 1 000 cu. ft. per sec. Mr. Chittenden.

It should be said that the figures for rainfall are made up from two stations, the only ones available, viz., Cedar Lake, west of the center of the water-shed, and Lester, just south of the eastern portion. Both these stations are in valleys, and probably do not represent accurately what took place in the hills. But the explanation of so large a freshet compared with the rainfall is in any event obvious. The month had been very rainy and the storage capacity of the water-shed was exhausted. There was a considerable quantity of snow in the hills, both on the ground and on the trees. The temperature was high, and the water from the snow came down with that from the rain; so that, in spite of the heavy layer of humus over-spreading the whole water-shed, and in spite of the presence of a considerable lake which has a moderating effect on freshets, the discharge rose and fell quite as rapidly in response to precipitation as on an eastern stream in the hilly country where the forests have been cleared away. Plate XLVI is a view of the water-shed.

Cedar River is the stream which Mr. Pinchot, in the January, 1908, number of the *Annals of the American Academy of Political and Social Science* (devoted to the subject of American Waterways), has compared with Owen Creek, Arizona. Both streams are given as having a water-shed of about 173 sq. miles; that of Owen Creek is barren and treeless, with much rock exposed, and the water flows off as from a roof. Little rain falls, and there is no record of the precipitation that caused the heavy freshet of 1896 which Mr. Pinchot cites; but, from all experience in that country, the storm was evidently in the nature of a cloudburst. There was a record of only about 15 in. of rainfall for the year at the nearest Weather Bureau station. The freshet cited was estimated at 9 000 cu. ft. per sec., or a little over 50 cu. ft. per sec. per sq. mile.

The data given for Cedar River in the flood of 1897 were as follows: Rainfall, 93 in. for the year, estimated at 150 in. in the mountains; maximum flood flow, 3 601 cu. ft. per sec., or 21 cu. ft. per sec. per sq. mile.

Of course any such comparison, as illustrating the effect of deforestation, is wholly inapplicable. It would even be as fair a comparison to take the City of Seattle, with its roofs and pavements. A legitimate method would be to compare a forested area with a deforested area in the same kind of country. The comparison as given omits all reference to distribution of rainfall, yet in Phœnix, in 1896, rain fell on only 51 days while in Seattle and vicinity it falls on the average 160 days in a year. Moreover, the flood flow of Cedar River, as stated, is evidently wholly in error, for the flood of 1897 is locally considered to have been greater than that of 1906 when it reached 10 800 cu. ft. per sec., or 75 cu. ft. per sec. per sq. mile. The area of

Mr. Chittenden.

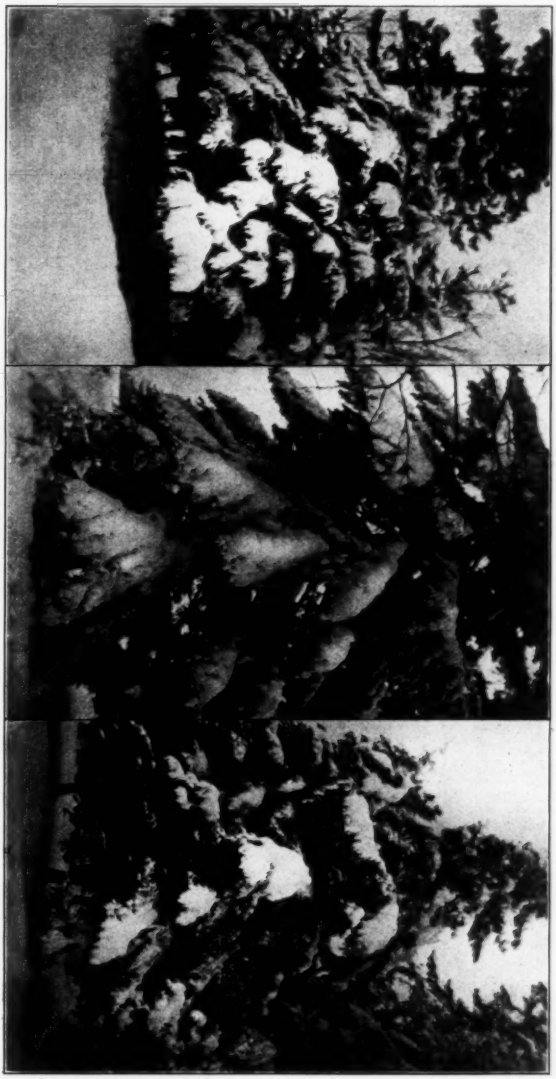
the Cedar River water-shed is overstated by 20%, and no mention of the lake is made. It appears, however, that, notwithstanding the unfitness of the parallel, and the defective data for Cedar River, the illustration stands decidedly against the argument which it was intended to enforce.

A recent freshet in the Skagit River, in which snow played very little part, and in which the rainfall was by no means excessive, still further confirms the view that the moderating effect of these forests on floods is much less than is popularly supposed. The rainfall at Sedro Wooley (the only station on the water-shed), which, for a week prior to November 16th, 1908, had been nothing, was 0.46 in. on the 16th, 1.11 in. on the 17th, 0.01 in. on the 18th, and 0.26 in. on the 19th. The corresponding gauge readings were 37, 48, 52 and 47.6 ft.—a total rise of 15 ft., the river reaching bank-full stage. The rainfall was doubtless heavier in the mountains, though records at three points outside the water-shed do not indicate that it was so. Mr. H. L. Devine, weather observer at Sedro, and for nineteen years a resident of that place, stated that the absence of snow alone prevented a most disastrous flood. The writer cannot account for the fact that such a rainfall could produce such a result in such a country, except upon the supposition that previous rains had left the forest bed well soaked, and also that, through long periods of time, the water had developed little channels under the débris through which it flowed away much more easily than would seem possible from superficial appearances. The Skagit River at Sedro has a rapid fall, and a 15-ft. rise in gauge height means a great increase in discharge.

How well the inhabitants of this region understand the danger involved in heavy snowfalls in the lower altitudes is well shown by what is transpiring at this writing. A week of frequently recurring heavy snow storms with light wind had loaded the trees and brushwood heavily with snow. (Plate XLVII.) This was followed by rain and warm winds, though very fortunately with intermittent cold snaps. But the farmers, understanding fully what would happen if the warm spell should be prolonged, immediately began strengthening the weak places in the river dikes and otherwise preparing themselves for a probable flood.

Proposition 4 is hardly comprehensive enough to cover the entire subject of snow-melting as treated in this paper, because it applies specifically to the Rocky Mountain region. A more complete summary of the general influence of forests upon the run-off from snow-melting is given in the following statement:

Snow has the effect of postponing the run-off from precipitation to a period subsequent to that in which the precipitation occurred. If the melting is accompanied by rain, the result is to add the run-off of two or more storms together.



SNOW ON EVERGREEN TREES.

Mr. Chittenden.

The forest increases the intensity of the run-off from snow-melting primarily by its effect upon the distribution of the snow, whereby the area exposed to the melting influences is increased over what it is in the open country where the snow is largely thrown into drifts.

The forest, by virtue of its shade, delays melting from the direct action of the sun, and tends to hold the snow until warm-weather conditions arrive, when the snow melts with great rapidity. This applies more particularly to the central Rocky Mountain region, where the forests are evergreen, and where the sun shines a great deal. It has a smaller application to the eastern deciduous forests, where there is less shade and less clear weather. Smaller still is its application on the Northwest Coast, on account of the lack of sunshine in the season of melting.

In the eastern forests, the flattened-out, and often frozen, layer of leaves from deciduous trees in a measure offsets the more general freezing of the ground in the open country in the matter of shedding the water from heavy rains and melting snow.

On the Pacific Coast, the wet condition of the snow and its tendency to cling to trees and underbrush give the warm ocean winds, common in that region, great effect in melting, and this circumstance adds materially to the intensity of the resulting freshets.

As a general rule, therefore, in all situations, the effect of forests upon the run-off from snow-melting is to intensify it.

After the above writing had been completed and forwarded for publication, a letter appeared in *Engineering News* for January 28th, by Jeremiah Ahern, M. Am. Soc. C. E., District Engineer, U. S. Reclamation Service, strongly confirming the writer's theory in regard to snow-melting in the mountains. He says that such snows always melt in the following order:

"(1) Snow on the unforested areas not collected in drifts.
"(2) Snow on the forest areas.
"(3) And last, snow in drifts scattered over the unforested areas."

He quotes the late Major John W. Powell as follows:

"When the mountain declivities are grassy slopes, the snows of winter drift behind ledges and cliffs and into great banks among the rocks, and they fill ravines and canyons, and are thus stored in compact bodies until they are melted by the summer suns and rains. But when forests stand on the slopes the snows are spread in comparatively thin sheets, and great surfaces of evaporation are presented to the sun and the wind. For all these reasons the forests of the upper regions are not advantageous to the people of the valleys, who depend on the streams for the fertilization of the farms."

PROPOSITION 5.

"Soil erosion does not result from forest cutting in itself, but from cultivation, using that term in a broad sense. The question of preventing such erosion or soil wash is altogether one of dispensing with cultivation

Mr. Chittenden.

or properly controlling it. The natural growth which always follows the destruction of a forest is fully as effective in preventing erosion, and even in retaining run-off, as the natural forest."

This proposition, like the one preceding, has been received with more or less protest, and exclamations of "impossible;" but a calm review of the discussion will disclose a complete failure to shake its essential correctness. Mr. Leighton characteristically tosses it aside with a promise that if the writer will accompany him to certain regions he will convince him; but the writer ventures to predict that, if the suggested visit were made, he would find, in practically every instance which might be pointed out, that the erosion was initiated by attempts to reduce the land to cultivation. In fact there is nothing about a tree 3 in. above the ground that has any influence on erosion. The only feature connected with the removal of timber, *per se*, that can induce erosion is the log roads developed in hauling it out. These, of course, may start washing which may develop into large gullies. But the primary cause of erosion is injudicious efforts at cultivation, and in no place is the fault more in evidence than in the region to which Mr. Leighton refers. A recent writer incidentally refers to this matter in the following language:

"Of all the crimes of poor tillage which have aroused the workers toward conservation; of all the reckless clearing of timber, burning of soil, washing away and eroding of fields; all the process of robbing the land of its fertility by endless succession of the same crops, the worst examples are to be found among these mountains."

The writer lays particular stress upon this point because the problem of erosion is a problem in cultivation. There must always be a large percentage of cleared land in all parts of the country to sustain the population. The problem is to handle this cultivation in such a way as to reduce soil wash to a minimum. Coupled with the associated problems of crop rotation, fertilization, etc., it is easily the most important conservation problem before the people to-day, out-ranking forestry, or water-power, or navigation. In the great majority of situations, nearly all classes of cultivation can be managed so as to prevent excessive erosion. In all but a very few, grass cover is an effective agent; as much so as the forest itself. But there are some soils which are so unstable that the scratch of a hoe leads to erosion, and undoubtedly such should be reserved for that class of vegetation which never requires extensive breaking of the soil, viz., the rearing of forests. This is a very different thing from the wholesale and sweeping assertions that tree cutting naturally and inevitably leads to erosion.

Mr. Le Baron raises the point that cultivation is a concomitant of deforestation, and that therefore the writer's distinction is not a valid one. But his statement is not correct, either as to fact or conclusion. Let him look out of a car window on any railroad in

the eastern section of our country and see the woodland in all directions. In much of this the virgin timber has all been cut away. Let him visit the vast pine-stripped areas of Michigan and Minnesota and the Southern States, and in fact examine the country in almost any direction, and he will see that the original cutting down of much of our timber has not been followed even proximately by cultivation. It is true that the extirpation of the forest is necessary to cultivation, but the erosion, where there is any, begins with and is caused by the cultivation. Mr. Pinchot says, in the same vein: "Whether one destroys the forest to cultivate the soil, or cultivates the soil after the forest is destroyed, makes no difference." As logically might he say that if the ground were cleared of trees for the building of a dam, the clearing would be the cause of water collecting in the reservoir. Mr. Chittenden.

The point is often made that the trees break the violence of storms so that they do not strike the ground direct. This argument is altogether trivial and inconsequential. Wind-driven rain does not affect the soil of fields covered with grass, grain or other crops, much as it may "lodge" and play havoc with the crop itself. Most precipitation falls in winds of moderate power. Snow falling, no matter how fierce the wind, never produces erosion. Finally, the point is quite irrelevant, because it is impossible to have tree cover for our towns, cultivated fields, and pasture land, anyway, and there is of course no objection to its presence on the remainder of the land.

The writer notes two instances in which officials of the Forestry Bureau and Geological Survey have confirmed the views expressed in his paper upon this subject. In a paper by Mr. W. W. Ashe, Forest Assistant, published in the preliminary report of the present Inland Waterways Commission, he says that, of the sediment borne along by our rivers, "agricultural lands contribute only a relatively insignificant part." This is very different from the thousand million tons of soil from our fields, worth a dollar a ton, which we have read of so much during the past two years.

In a recent well-prepared article* by Mr. Herman Stabler, Assistant Engineer, U. S. Geological Survey, it was shown that the soil erosion above the proposed reservoirs on the Ohio water-shed under present conditions would fill up these reservoirs, if built, at an average rate of only 10% in 835 years, or 50% in 4 000 years. For the Monongahela, the period for 10% filling is 1 260 years; and for the Allegheny, 2 410 years; yet the water-shed of the first of these streams is over 50% deforested and that of the other over 60 per cent. These figures have a very important bearing upon the question here considered. They completely refute the claim so strenuously put forth that deforestation at the sources of these streams is producing ruinous erosion, and that the preservation and extension of the forested areas is absolutely

* *Engineering News*, December 10th, 1908.

Mr. Chittenden.

necessary as an adjunct to reservoir construction. Secretary Wilson's report, already quoted, says: "No matter what its purpose or design, any reservoir system developed in the Southern Appalachians is foredoomed to failure unless the watersheds that feed it are kept under forest;" and Mr. Leighton—"the reservoirs will not be worth a minute's time nor a cent of money unless the forests are retained." Yet it seems that on the Cumberland and Tennessee, with deforestation already far advanced, it will take about 700 years to fill the reservoirs 10%, and of course only a small portion of this can be traced to deforestation.

The silt measurements of these streams also confirm, though from another point of view, the writer's conclusions, from observation and study of the rivers themselves, that our navigable streams are not shoaling appreciably more than formerly.

At this point reference may properly be made to an argument advanced by two or three parties to this discussion, that soil cover is necessary over rocks because of its aid in disintegrating them, and also that trees are important in such places for the same reason and for the added reason that, by splitting up the rocks, they facilitate the ingress of water and its storage in the ground. In arguments of this kind one clearly traces the mental habit of the geologist whose very calling directs his study to the rocks of the earth and leads him to magnify both the extent and importance of those localities where rock is near the surface. Whatever force there may be in the argument itself is neutralized by its very limited application. Forest roots do not penetrate to the underlying rock, except to a very small extent, even in mountainous countries. In clearing the routes for at least a hundred miles of road in dense forest in the heart of the Rocky Mountains the writer does not believe that 5% of the trees removed penetrated to rock. Taking the whole country over, it cannot be that even one-tenth of 1% of the trees have any influence on the underlying rock. And so it is of soil covering; the areas where rock *in situ* lies within reach of the plow, or even within 2 ft. of the surface are very limited, and play an insignificant part in the general economy of the soil.

PROPOSITION 6.

"As a general proposition, climate, and particularly precipitation, have not been appreciably modified by the progress of settlement and the consequent clearing of land, and there is no sufficient reason, theoretically, why such a result should ensue."

The correctness of this proposition seems to be generally conceded by those who have carefully studied the question. For every rainfall record that forms an apparent exception, one can be found to offset it. Both in this country and in Europe long-time records of precipitation show little change, and certainly none in the direction of

decrease. Simply as an illustration of this general truth, two of the longest records which the writer has been able to find in our own country are given in Table 23. In deference to Mr. Leighton's penchant for 10-year periods, the means for each decade are also given, though in a few cases they are based upon partial records. Mr. Chittenden.

TABLE 23.—RECORDS OF RAINFALL AT PHILADELPHIA, PA., AND MARIETTA, OHIO.

Year.	Philadelphia	Marietta.	Year.	Philadelphia.	Marietta.	Year.	Philadelphia.	Marietta.
1811	34.97	.....	1844	40.17	36.64	1876	47.39	48.19
1812	39.30	.....	1845	40.02	33.90	1877	37.26	34.76
1813	35.63	.....	1846	44.39	46.27	1878	34.53	37.53
1814	43.14	.....	1847	45.09	52.30	1879	36.75	30.50
1815	34.67	.....	1848	35.00	43.18	1880	33.58	46.36
1816	27.95	....	1849	42.09	42.89	Mean	42.69	35.99
1817	36.01	....	1850	54.54	52.36	1881	30.21	36.78
1818	30.18	50.92	Mean	45.22	43.42	1882	45.58	59.96
1819	23.35	36.30	1851	35.50	34.94	1883	39.17	48.62
1820	39.61	39.11	1852	45.75	46.50	1884	39.34	38.54
Mean	34.48	42.11	1853	40.66	37.04	1885	33.53	41.68
1821	32.18	43.32	1854	40.18	38.80	1886	37.24	42.14
1822	29.86	43.38	1855	44.09	45.75	1887	42.17	37.32
1823	41.85	.....	1856	33.93	32.46	1888	44.06	56.28
1824	38.74	.....	1857	48.29	40.64	1889	50.60	40.95
1825	29.57	.....	1858	39.85	61.84	1890	34.02	60.99
1826	36.15	.....	1859	58.12	48.55	Mean	39.59	46.33
1827	38.50	.....	1860	44.09	39.48	1891	38.19	40.76
1828	37.97	49.50	Mean	43.05	42.60	1892	34.78	34.83
1829	41.85	39.52	1861	46.44	46.42	1893	37.65	39.94
1830	45.07	37.26	1862	45.01	42.71	1894	40.34	30.08
Mean	37.17	42.60	1863	49.19	37.07	1895	31.01	26.61
1831	44.94	53.54	1864	46.00	40.94	1896	32.15	.....
1832	39.87	48.33	1865	56.26	48.84	1897	42.04	41.41
1833	48.55	40.37	1866	45.26	47.37	1898	49.23	48.07
1834	34.24	34.66	1867	61.19	46.71	1899	39.96	43.73
1835	39.30	42.46	1868	51.40	50.06	1900	40.91	38.43
1836	42.66	36.75	1869	48.86	42.86	Mean	38.63	38.20
1837	39.04	43.86	1870	44.11	40.18	1901	45.54	37.62
1838	45.24	35.48	Mean	49.37	44.31	1902	49.76	.....
1839	43.74	33.32	1871	47.32	29.02	1903	41.50	41.96
1840	47.40	39.09	1872	48.36	.....	1904	39.76	26.01
Mean	42.50	40.79	1873	55.28	47.98	1905	41.61	46.38
1841	55.50	42.82	1874	46.25	39.57	1906	51.87	40.63
1842	48.54	42.07	1875	40.22	46.04	1907	.....	53.14
1843	46.91	41.76				Mean	45.01	40.96

Means for whole period — Philadelphia, 41.63; Marietta, 42.34.

Mr. George P. Marsh, in "The Earth as Modified by Human Action," presents the strongest possible arguments for the conventional forest theory—in fact, his zeal in this cause often leads him into extravagances that rival those of the present day; but upon this particular subject he is compelled to say:

"I am unable to refer to a single instance where the records of the rain gauge, for a considerable period before and after the felling or planting of extensive woods, can be appealed to in support of either side of the question. The scientific reputation of many writers who

Mr. Chittenden.

have maintained that precipitation has been diminished in particular localities by the destruction of forests, or augmented by planting them, has led the public to suppose that their assertions rested upon sufficient proof. I cannot affirm that in none of those cases did such proof exist, but I am not aware that it has ever been produced."

Perfectly applicable is this statement to the common theories of the present day.

It is also claimed that precipitation is more irregular, but here again evidence is lacking, and, such as there is, is conflicting. There is nothing of sufficient duration or accuracy to enable one to draw positive conclusions, except that whatever changes may have resulted are of very small magnitude. The distribution of rainfall throughout the year is very irregular, and upon this fact Mr. Leighton and others have built up their theory of increased flood frequencies following deforestation. It might possibly be claimed that this irregularity itself is due to deforestation, but this is negatived by the fact that the greatest irregularity in the numerous records cited by Dr. McGee and Mr. Leighton occurred on those water-sheds where there had been the least change in those years in forest areas.

The claim often advanced, that broad general changes in climate have resulted from changes wrought by Man on the surface of the earth in particular localities, is likewise without substantial foundation. The writer believes that a careful study of the question, with the same rules of evidence that would be applied to any other subject, will convince any one of the substantial correctness of the following statement by Professor Cleveland Abbé, of the U. S. Weather Bureau, in his article on climate in the International Encyclopedia:

"There is no well-authenticated case of an appreciable change of climate within the past two thousand years. The researches of Eginitis on the climate of Greece seem to establish this principle beyond doubt. Neither is it possible that any change on the surface of the earth due to man—such as deforestation, reforestation, agriculture, canals, railroads, or telegraph lines—can have had anything more than the slightest local effect, if any, on climatic phenomena that depend upon the action of the whole atmosphere."

One of the most common of popular fallacies is this belief in change of climate. In every community probably the majority of people believe that material changes have occurred within a generation. Most of us can remember when it was generally thought that the climate of Western Nebraska and Kansas was changing, and rain was becoming more frequent as a result of settlement and cultivation. A succession of more than average wet years was responsible for this belief, and many settlers moved to that country on the strength of it. But after a while normal conditions returned—perhaps the pendulum swung the other way—and many a settler was forced to leave the country. These facts are matters of official record.

Mr. Chittenden.

It would be, indeed, a most welcome fact, if it were true, that, by introducing cultivation into the arid regions, rainfall could be increased; but it would be less welcome if it had to be accompanied by another fact, that the settlement of the humid regions reduced precipitation.

Mr. Leighton takes exception to the writer's statement that seasons of drought are more to be dreaded than seasons of flood. He states that the flood damages for the year 1907 amounted to $260 000 000. He does not say whether this means direct damages, or whether it is made up in part of indirect or inferential losses, such as interference with transportation, temporary depreciation of real estate, and the like. The figure looks pretty large for direct damages alone. Nothing is said, either, as to the great compensating effect of fertilization of bottom land due to general overflow. It is well known that the effects of such overflows in increased yield of crops are noticeable for several years after their occurrence. Their aggregate value is undoubtedly large, and constitutes a material offset against direct damages. In many parts of the world these overflows are a regular reliance, and one of the evil results of the levee system, wherever used, is that it cuts off this means of periodic renewal of the soil. But taking the above figures as representing actual and uncompensated loss for this one year (they certainly do not represent the average annual loss), let them be compared with the effects of the shrinkage of crops through drought. The value of the agricultural products of the United States for the year 1908 was more than $7 750 000 000. A skrinkage of a trifle more than 3% would equal the above flood loss, and it is well known that a not excessive drought will cause a shrinkage far in excess of this amount. Famines, the world over, and throughout recorded history, have generally resulted from widespread deficiency of rain, particularly where such deficiency has extended through several years.

The constantly increasing losses from floods, with the settlement and development of the country, are often cited as evidence that floods are increasing. But the fallacy of such reasoning is strikingly illustrated by a single example. In 1844 occurred the greatest flood on record in the Missouri and Kaw Rivers at their confluence. The damage was insignificant, because there was little property there. The next greatest flood was in 1903, and the damage approximated $30 000 000. Kansas City had been built in the path of the flood. Care should be taken, in comparisons of this sort, not to ascribe to increasing flood heights or frequencies losses which are due to Man's operations in placing property in the way of floods.

Messrs. Pinchot and Willis have referred to the cooler status of the forests as inducing precipitation, Professor Willis citing the evidence of aeronauts that the air is cooler over forests than in the open. But the inconclusive character of evidence like this is apparent at a

Mr. Chittenden.

glance. It applies only to hot weather and to the air near the surface of the ground. It is certainly not true of the fall, winter, and spring seasons, when most of the rain and all the snow falls. It is probably not true even of summer storms of considerable duration. Whatever influence there is of this kind is small even in summer showers. The example, cited by a recent writer in *Engineering News*, of showers soaking the forests but leaving the clearings untouched—like Gideon's fleece, saturated with dew while it is "dry upon all the earth beside"—requires something more than a bald statement to substantiate it. If there is any such tendency it may be questioned if it is not more than offset by the greater absorptive power of the forest than that of the open country at such times.

It should be carefully borne in mind, in any discussion of this subject, that floods and low waters result primarily from the quantity and distribution of precipitation. It is rarely necessary to go beyond this simple fact for an explanation; but apparently because climate is still one of those natural phenomena over which Man has acquired no control, the tendency is to ignore it and attribute to other causes results for which it is alone responsible. The greatest discovery or advance in scientific knowledge, so far as the practical welfare of Mankind is concerned, that the world is likely ever to see (if it should see this) will be of some means of controlling the weather, and particularly precipitation. Many experiments have been made in this direction, but so far without appreciable success.*

PROPOSITION 7.

"The percentage of annual run-off to rainfall has been slightly increased by deforestation and cultivation."

The writer submits this proposition simply as an expression of his own opinion, without many confirmatory data. The 20-year record of the Connecticut at Holyoke,† by Clemens Herschel, M. Am. Soc. C. E., seems to confirm it on that stream, though the period is short. The low-water discharge of the Ohio seems to be as great and possibly greater than formerly, particularly if there be included the very large consumption for human use which would otherwise get into that stream. The writer does not believe that there is any large increase in the percentage of run-off over that of former times, but he believes, in any event, that it has not diminished.

* Though admittedly irrelevant, the interesting character of the following item justifies its insertion here, as another example of the old saying that "There is nothing new under the sun." Everyone is familiar with the superstition (possibly it deserves a better name) that great battles produce rain. The vibrating effect upon the atmosphere of the multitudinous detonations of artillery is generally ascribed as the cause. Read this from Plutarch, who flourished 45–125 A.D.

"It is an observation also, that extraordinary rains pretty generally fall after great battles; whether it be that some divine power thus washes and cleanses the polluted earth with showers from above, or that moisture and heavy evaporation, steaming forth from the blood and corruption, thickens the air, which naturally is subject to alterations from the smallest causes."

† *Transactions*, Am. Soc. C. E., Vol. LVIII, p. 31.

Mr. Chittenden.

Having reviewed the seven fundamental conclusions deduced from his original argument, the writer will ask the attention of those who have considered his views "extreme" to the conservatism which has marked every stage of his reasoning. More than once he has called attention to the unwisdom of building positive theories upon any one of the multitudinous details of this subject, in which definite data are still so lacking; and the general result of his argument was summed up in the following sentence, which he would here print in italics if the rules of the Society would permit: "The difference between past and present conditions is not great." The forest with its bed of humus is replaced by the cultivated field which quite equals it in absorptive power. The influence of forest growth upon evaporation is offset by that of growing crops. The greater parching effect of the direct rays of the sun upon the surface of the ground in the open country is relieved to some extent by the deposition of dew. If the forests are cooler in summer and possibly induce greater precipitation, they are warmer at other seasons and possibly have the contrary effect. And so, when we go to the great rivers to gather up the net result of these manifold influences, we find things very much as they used to be. It should be a matter of profound satisfaction that this is so. It is a pleasing picture to turn to after the saturnalia of horrors—"waste," "desolation" and "ruin"—to which we have been treated during the past two years by the forestry propaganda.

This paper had "particular reference to navigable rivers," and its general conclusions must be read with reference to our large streams. The writer holds that there is nothing in forestry that can lessen in any material degree the cost of works necessary for flood protection and navigation improvement. An important point in the paper, which has been passed over in silence by its critics, is that, even if the claims of forestry advocates in this connection were true, they would still offer no hope because they cannot be generally applied. It will never be possible to increase our present woodland area. The requirements of cultivation and occupancy will rather cause it to be reduced. There may be a shifting of wooded areas, a clearing-off of present woodland and a planting of new, but the grand total cannot be increased. Not only, therefore, are forestry advocates filling the public mind with erroneous theories on this subject, but they would be unable to apply those theories even if they were correct. They would doubtless reply to this, however, by saying that it is not expected to restore original conditions to any marked degree, but only to prevent a further departure from them.

The attitude assumed by some of the writer's critics is that he is hostile to forestry expansion and development. No candid reader of his paper can come to any such conclusion. The writer has made it very plain that he is not only friendly to the cause of forestry, but is

Mr. Chittenden.

a thorough believer in its great importance. He has not said a word against the interests of legitimate forestry, but he has attacked a spurious forestry which in these later days is trying to substitute a shadow for a reality and make the shadow the main issue. Deeply significant is the statement by Mr. Todd that:

"There seems to be a great popular belief, even among some residents of the Lower Mississippi Valley, that deforestation is largely responsible for most of the recent great floods."

Suppose that this popular belief, which finds its source in the scientific bureaus at Washington, were to be carried to its logical conclusion, and the people of the valley were to spend money provided for flood protection in pursuing the will-o'-the-wisp of reforestation. Could the teaching that would lead to such a result, and jeopardize life and property for a chimera, be considered scarcely less than criminal? Happily, the sober counsel of the engineer will always stand in the way of any such foolhardy project as this; and although there is every reason to believe that, if the suggested bond issue of $500 000 000 for improving our navigable waterways were made, a large slice would be asked for, for forestry purposes, it is not to be believed that the better judgment of the country will ever sanction it.

The writer insists that forestry should stand on its own bottom, and not bolster itself up by the aid of interests with which it has no connection. The preservation of timber for this and future generations, the maintaining of woodland for the pleasure of the people, for their protection against storms, and in many places as the most available preventive of soil erosion and the drifting of sand—these are the true purposes of forestry, and to the promotion of these ends its propaganda should in the main be confined.

In the further matter of public policy, involved in the location of our national forests, the writer willingly defers to Mr. Pinchot's more extended study, but he nevertheless desires that Mr. Pinchot's statement, that only existing virgin forests are adapted for future reserves, be clearly understood. Possibly the writer has been unduly influenced, through his experience in mountain forests, by the great drawback involved in the inaccessibility of such regions. Hundreds of times he has heard visitors to the Yellowstone, in riding through those extensive fields of down timber, remark in substance, "What a pity it is that all this timber cannot be near New York or Boston, where it could be used;" and anyone who has seen how every scrap of wood is gathered up in foreign countries and turned to use, and how eventually the same will be true of this country, cannot but realize the importance of having our forests convenient to the homes of the people. And when he considers the greatly increased cost of lumber from getting it out of inaccessible places, and the further cost of transporting it over great distances, he realizes still more fully the same necessity.

Mr. Chittenden.

A tree conveniently located for access and use is worth two, or five, or ten, in the mountains. Add to the advantages from the above points of view those of the enjoyment of the people from access to the forests, the value of forests as wind-breaks and shelters, their greater immunity from fire if in detached areas than in continuous areas, and there may seem to be after all some merit in the writer's idea of a wide distribution. Some have construed the writer's words on this subject to mean that he would devote good agricultural land to this purpose. He expressed no such thought. In almost every locality there are lands of little agricultural value that could be devoted to this purpose without unduly restricting areas of cultivation.

The writer can hardly believe, and is quite certain that the country at large does not believe, that good results cannot be obtained in the development of forests upon our cut-over lands throughout the country. Mr. Pinchot says that a forest plantation can never take the place of the natural forest. Very true, but the forest primeval is gone forever, or soon will be. Even such as are retained will no longer be "primeval" after a period of cutting. It will be necessary here, as in Europe, to rear up new forests, and this in fact is constantly urged in current forestry literature. If this is the revamping of an old idea, let it continue to be revamped until it becomes the main idea. It need not be imagined that the people of the country will consent to be taxed for the purchase and maintenance of forests in the eastern mountains, and stop there. If forests are necessary and if general taxation is to maintain them, their benefits must be brought home to all the people as nearly as possible. It seems to the writer very desirable that this subject be thoroughly considered and a general policy adopted by Congress before it launches out upon some partial or local measure.*

Concerning the second section of the paper—the function of reservoirs in the control of stream flow—very little has been brought out in the discussion that requires attention. By what reasoning a few of his critics have concluded that the writer is opposed to the general idea of water storage on a large scale, it is impossible to conceive. No word in the paper justifies such an inference. In fact this particular subject has always been a professional hobby of the writer's, and no one appreciates more fully than he its possibilities and the importance of locating and constructing such reservoirs as rapidly as conditions will justify. The example of the State of New York in taking up the matter with a view of storing its waters and rendering them available for power is one that should be followed by other States and by the Government, in their respective spheres.

* The writer is glad to note a desire on the part of Congress to enter upon this work on broad lines without restricting it to any particular section of the country. The Weeks bill, favorably reported on January 26th, is a step in the right direction. It is to be hoped that this, or some equally comprehensive measure, will become a law.

Mr. Chittenden.

The writer's criticism was directed solely against the visionary aspects of the case and the bold effort that was being made to sidetrack important practical projects in the interest of a stupendous and uncertain scheme. An estimate of $125 000 000, held out in dazzling figures before the people, is now withdrawn in favor of the writer's estimate of $500 000 000. This is exactly the amount of the bond issue now being urged to bring all the waterways of the country into prime condition. If this reservoir system were to be built, where would the remainder of the country come in?

The time is now at hand when some of these reservoirs should be built; the low-water conditions of 1908 demonstrate this necessity. The time may come when they will all be built, but it will only be when their utility has been demonstrated on other grounds than flood protection and navigation. If ever built, they will unquestionably be of value to both those interests, but they cannot be justified on their account alone.

Arthur P. Davis, M. Am. Soc. C. E., Chief Engineer, U. S. Reclamation Service,* calls attention to the great value of the reservoirs being built for irrigation in controlling floods on the streams below them. Mr. Davis' views throughout are characterized by a clear comprehension of the possibilities and limitations of reservoirs in promoting one purpose though built for another. His anticipations will doubtless be fully realized.

The writer is glad to note in a recent issue of one of the technical journals that steps are being taken to determine a more definite estimate of the value of our natural water-powers. It is indeed important that this be done. Whatever may have been Mr. Leighton's intention in regard to the $20 value, as used in his numerous writings upon the subject, the understanding which the average reader has gathered is that undeveloped powers (that is, minus power-plant installation) would be worth at least $20 to the Government.

Having considered the more general aspects of the discussion, the writer will now take up a few of the special points brought out by the several contributors. He will take these up seriatim as presented, and not attempt to reduce them to classification. In large part the adverse criticisms of his paper are based upon a misunderstanding of what the writer said. The first reading has aroused a feeling of opposition among those who have always thought the other way. Instead of weighing his arguments, they have frequently replied either by flat contradiction or the citation of exceptions, forgetting that an exception does not ordinarily invalidate a rule. There will be no attempt to notice all these criticisms, and the reader will simply be asked to compare them with the text to which they relate.

* *The Engineering Record*, November 18th, 1908, p. 558.

Mr. Chittenden.

The opening sentence in Mr. Collingwood's criticism has a significance which the writer probably did not intend. His reference to "conclusions" as "firmly established" indicates that he is under the impression that the current forestry theories are so established. A similar suggestion is made in a recent State paper in which the writer's views are characterized as being "contrary to the experience of mankind" and "opposed to all the recent work of the scientific bureaus of the Government." Professor Swain, in an elaborate paper prepared at the request of Governor Guild of Massachusetts to controvert the writer's arguments, expresses the same opinion. What are the facts upon this point?

Forestry has been a living issue in France for nearly a century. Between 1850 and 1870 the subject was much discussed *pro et con*, forestry advocates being very pronounced in their views that forests exercise a marked regulative effect upon streams, and many prominent engineers taking exactly the opposite view. In 1857 M. F. Vallée published a paper upon this subject which was translated in 1873* by Captain Charles J. Allen, Corps of Engineers, U. S. A., and printed under the auspices of the Engineer Department of the Army. M. Vallée goes into the subject exhaustively, traversing the entire argument that forests have a beneficial effect upon either high or low water. He cites many interesting examples, relating to floods, springs, low waters, etc. Professor Swain refers slightingly to this paper, saying that it had no effect on public opinion at the time. Be that as it may, M. Vallée was not alone in his views by any means, and an event occurred at about that time which shows that his views were adopted practically, whatever may have been the opinions of doctrinaires.

After the great flood of 1856 in France, elaborate studies were made of the flood problems of several of the rivers, as related in the writer's paper. The subject of reforestation, as a means of reducing flood heights, was considered for both the Rhône and the Loire and rejected as impracticable. The comments upon the sources of popular opinion on the subject, its lack of foundation, the fact that the great floods cannot be modified by this or that change which Man may make on the surface of the earth, are all pointed out very effectively. This is probably the first example in which reforestation has been urged as a practical means of regulating the flow of great rivers, and it was rejected summarily. The example so set has been followed ever since.

About this same time appeared an elaborate work by M. Champion, giving a history of the floods of French rivers since the sixth century. It showed that floods had been diminishing, so far as there was any change, this tendency in the case of the Seine being very pronounced. Thus the gauge at La Tournelle Bridge, Paris, showed the following mean heights for five half-centuries from the year 1600: 8.39, 8.03, 7.72, 6.83 and 6.47 meters.

* In the paper the writer erroneously gave the date of publication as 1873.

Mr. Chittenden.

In 1864 appeared Marsh's book "Man and Nature," which was revised in 1884 under the title, "The Earth as Modified by Human Action." This work set forth the ultra-forest theory so closely on the lines that we are now familiar with, that the writer has appended to this discussion a brief extract, on account of its historic value.

In 1873 appeared a treatise by Sir Gustav Wex, presented to the Austrian Society of Engineers and Architects, "On the Decrease of Water in Springs, Creeks, and Rivers Contemporaneously with an Increase in Height of Floods in Cultivated Countries." This work set forth in elaborate form the conventional forest theory. But its propositions were disputed to such an extent by "engineers and hydraulic experts" that Wex issued another and more elaborate treatise in 1879. Its reception, however, was no more favorable than that of his first work.

In our own country, in 1885, Colonel Thomas P. Roberts presented an elaborate paper before the American Forestry Congress, based upon river records, showing that the commonly accepted theories had no foundation in fact. This paper is historically important, not only as an isolated example of courage in opposing an almost universal popular opinion, but because it was the first to call attention to the compensating effect of summer showers in the open country in offsetting any possible deficiency in the flow of springs as compared with that of the forest during periods of drought. A brief extract from this paper is given in the Appendix.

In 1896 appeared the article by Mr. R. L. Fulton in *Science* which the writer has referred to in his paper. It is probably the first publication that sets forth, substantially in accordance with the facts, the action of mountain forests upon the run-off from snow-melting. Owing to its intrinsic and historic value, the main portion of this article is given in the Appendix.

M. Lauda's report upon the great Danube floods of 1897 and 1899 is referred to in the writer's paper. A lengthy abstract from the report was translated by the writer.* A perusal of this abstract will show how little value that eminent authority places upon forests as regulators of stream flow.

At the 10th International Congress of Navigation, held at Milan in 1905, this very subject was one of the questions considered. Five countries—Russia, Germany, France, Austria, and Italy—were represented in the discussion, and the consensus of opinion was that, important as forests might be from other points of view, they had no appreciable effect upon the regimen of great rivers. It was held, however, that forests are an important means of preventing erosion on mountain slopes.

To all these authorities should be added the important negative

* *Engineering News*, October 29th, 1908.

evidence that there seems to be no instance on record in this or any other country where a scheme for the improvement or regulation of a navigable stream has embraced as an essential feature the reforesting of any part of its water-shed. Mr. Chittenden.

Such is a brief summary of the evidence concerning the "experience of mankind" on this particular subject. The "firmly established" conclusions are no conclusions at all. On the one hand are the forestry advocates in this and other countries claiming that the welfare of our rivers depends upon the preservation of our forests; on the other is the practical engineer who holds that our rivers cannot be regulated by any such means. If Mr. Collingwood had said that these views are firmly established in popular thought he would have been entirely correct; but that is not a sufficient reason for believing them to be true. Whether a popular belief is correct or not depends upon how it originated. Since the appearance of this paper many have said or written to the writer that they had never even thought that there were two sides to the question; that they had accepted unquestioningly the current theories, as put forth by writers and lecturers, without investigating at all. Manifestly, such a belief is worth as much as the source from which it is derived and no more. Remember that "truth does not depend upon the number of its adherents." Authority cannot change the laws of Nature, nor can the most implicit belief in the influence of forests upon stream flow make that influence a fact where it does not exist.

As to the work of the scientific bureaus, upon this particular subject, it is extremely difficult to determine precisely what it is or what their views are. It is an excellent example in which "doctors disagree." At one time it is held that forests diminish floods, and at another that no "well-informed" person entertains such a view. It was announced not long ago that the forest bed is a great reservoir; now, that it is held to be such in only a "nominal sense." Deforestation is said, in one breath, to increase the height and shorten the duration of freshets, and, in the next, to increase both height and duration. One authority declares that the lower layers of the soil are always drier in the forest than in the open, while others strenuously insist that the contrary is the case. A little while ago the country was told that a thousand million tons of soil are yearly washing from our agricultural lands into the sea, while just recently it is stated that only an insignificant portion comes from that source. In a formal public document it is stated that deforestation of the Appalachian slopes would speedily destroy any reservoir that might be built in that region; and in an equally formal professional paper it is shown that, even where deforestation already covers 50 and 60% of the land, it would take from 10 000 to 20 000 years to fill the proposed reservoirs with sediment. Some authorities hold that rainfall and climate are changing for the

Mr. Chittenden.

worse through deforestation; others, equally high, hold that the history of the past, as well as modern records, affords no warrant for any such claim.

It would, of course, be entirely unjust to ascribe this discord to any deficiency of qualifications, knowledge, or industry on the part of our scientific bureaus; no one acquainted with their work would admit that. It is forced upon them by the exigencies of a "cause." Of late, the prominent feature of this cause has been the White Mountain-Appalachian project. Every argument that could be devised to influence public opinion in favor of this project has been used; and a practical necessity has forced the stream-flow function of forests in this connection prominently to the front. Legal authorities have held that this forest reserve could not be created as a timber reserve, pure and simple, because, forsooth, an instrument written a century and a quarter ago says it cannot be done unless such reserve will also promote the navigability of the rivers that flow from it. Thus a feature of the forestry propaganda, which is a wholly subordinate one, is made the chief stone of the corner. Inasmuch as the very foundations upon which it is sought to lay it are to a very great extent fictitious and non-existent, it is no wonder that discord and confusion have resulted in trying to build upon them; and the Engineering Profession, at least, will probably feel that the "recent work" of the scientific bureaus upon this particular subject is not exactly a safe guide.

Mr. Collingwood, with the perfect simplicity of the typical forestry enthusiast, after citing certain changes in the Chemung River, asks: "If the cutting of the timber did not do it, what was it?" Again, "after this, therefore on account of this." Has Mr. Collingwood ever inquired whether there might not be some other cause? Has he examined into the nature of Man's operations along that river, the effects of cultivation, etc.? He admits that he has no data of value as to the earlier condition of the stream, but only as to its later condition. Is it not a fact that much of the havoc he mentions was wrought by a single flood, that of 1889, the year of the Johnstown flood, when 8 in. of rain fell in 3 days in the hills around Elmira? According to his own statement, the rafting of logs, which naturally marks the active inroad into the virgin timber, ceased nearly 60 years ago, and only the cutting of hardwood has progressed since. Yet the great changes which he notes have taken place within 20 years. Does Mr. Collingwood consider evidence of this kind very convincing?

The writer is quite willing to accept what Mr. Le Baron says of the precipitation in tropical countries; but it manifestly does not apply to our northern climate, which alone is considered in this paper.

Mr. Le Baron refers to possible development of forests on irri-

gated lands as opposed to the writer's statement that the aggregate forest area of our country cannot be increased. As soon as Mr. Le Baron demonstrates the practicability of a large development of genuine forest in the arid regions the writer will modify his statement proportionately. As a general rule, lands under irrigation are devoted to intensive farming, and are too valuable to be converted into forest; though Mr. Johnston intimates the practicability of forest extension by this means. Mr. Chittenden.

Mr. Le Baron is very much astray in his inference regarding the saving of cost of installation of water-powers by the use of Government dams. In the first place, this would not apply to the great majority of water-power developments, if such developments are to be made on a really extensive scale. In the second place, the sites of locks and dams are not favorable on account of the low head and the great relative fluctuation. Compared with the power attainable, the installation is necessarily much more costly than where the same power-house and machinery would yield several times more power.

The writer notes the interesting point brought out by Mr. Todd in regard to the percentage of run-off as affected by slope. That a greater percentage of rainfall runs off from flat than from steep slopes is at first not easy to admit, but where the soil is swampy and ground storage is not available, it is quite probable that this is true. The example is another proof of the necessity of care in making generalizations upon so uncertain and variable a subject.

When Professor Swain says that "the author seems to be attempting to convince us that, not only forests, but reservoirs, increase the violence of freshets," he says something that has no substantial warrant anywhere in the paper. The whole tenor of the argument is that the difference between the past and present is not great, although the records show that we actually had greater floods before the forests were cut than we now have. Only in the effect of forests on snow-melting, as described by the writer, can Professor Swain find any support for his remark, and only in rare combinations do reservoirs operate to increase freshets.

Professor Swain does not understand the writer's reference to the suggested reservoir system for the River Rhône in France. If he will examine page 39, *et seq.*, House Document No. 141, 55th Congress, 2d Session, or the French reports upon this subject, he will find the matter fully explained. With characteristic detail, the French engineers worked out a system of reservoirs for that stream which was ample to protect the valleys of the tributaries and the upper courses of the main stream; but they found, on applying it to a great flood

Mr. Chittenden.

like that of 1856, that it would produce a greater overflow than actually occurred in the lower stretches of the valley. This was due to the more extensive combination of tributary flow from prolonging the run-off of the various affluents.

Professor Swain says, in reference to the writer's statement that a greater forest area in Western Montana would have aggravated the flood of 1908, that this "is a mere statement of the author's opinion, entirely without proof, and undoubtedly incapable of a proof." It is not a matter of opinon at all, but a clear, logical deduction, as capable of proof as any proposition in mathematics. The facts are that there were extensive forest tracts in the region affected by this flood. These forests held the snow, and there was a large mass of it on the ground when the heavy rains came. The melting of these snows added materially to the flood. If Professor Swain doubts these facts, he can corroborate them by reference to the Weather Bureau records. It is also a fact, which he can readily verify, that in the neighborhood of these forests there are extensive tracts of non-wooded lands similarly conditioned as to topography and altitude to the forested lands. Now if these tracts had also been covered with forests, the ground within them would have been covered with snow, as the ground in the existing forests was; that snow would have melted as the snow actually there did; and in the same way would have added its quota to the flood. *Q. E. D.*

Professor Swain has cited Professor Carpenter on the subject of snow-melting. The writer has often drawn upon the ample fund of information which Professor Carpenter has accumulated, and has conferred with him on more than one occasion. It is a pleasure to bear testimony to the value of his opinions upon any subject. It is possible, however, that he may not have studied closely the phase of this question presented by the writer. In any event, the citations given by Professor Swain are not sufficient to carry conviction. There are several important questions that need to be answered in that connection. The diurnal fluctuation of the streams due to snow-melting is precisely the matter upon which the writer has laid stress in his paper. The great safety device of Nature in letting down the snows in these mountains is the sun and the open country drifts. It is as if a care-taker of some great reservoir hoisted the gates for an hour or so each day, letting out a quantity of water and not closing them again until it had flowed away. The diurnal rise and fall may be a source of some inconvenience at head-gates, but this is really a trivial matter after all, and a hundred miles down the stream largely disappears. The writer doubts whether Professor Carpenter ever saw a real flood from this cause; but he has seen many a flood which has come down when the forests gave up their snow. Why has not this fact made an impression? And has he not often seen drifts in the open

country of his mountains long after every vestige had disappeared from the forests? Is it not true that these drifts and those higher up are a valuable resource long after the forest snows are gone? Mr. Chittenden.

Mr. Willis states that the forest prevents from 20 to 40% of the rain from reaching the ground, depending upon conditions. The range is far wider than this. In the heat of summer, and with light showers, forests often hold back nearly 100% of precipitation; but when it comes to cold, heavy rains, from 1 to 3 in. in a day, and in deciduous forests where, for large portions of the year, there are no leaves on the trees, will any one venture to say that the forests prevent even 1% of the rain from reaching the ground? Yet it is with these very extremes, as the writer has pointed out with emphasis, that our practical problems in river control are concerned.

The writer would request those interested in this discussion to read carefully the quotation given from Ernst Ebermayer early in Mr. Willis' discussion. It is a plain case of being unwilling to swallow one's own doctrine. If that quotation means anything, it means that the forest prevents rain-water from penetrating the ground as readily as in the open country. But, "the forest on the mountain differs very decidedly from that on the plain in regard to water control," and "a factor is introduced through which wooded mountain slopes receive a much larger amount of water than bare unwooded water-sheds." What is the factor? What is the difference between mountain and plains forests in regard to water control? The writer maintains that, so far as there is any difference, it is all in favor of the plains forests. For the same forest bed, the retentive capacity diminishes as the slope increases. Anyone can verify this fact by experiment. Far from the mountain forest being more effective in resisting run-off, the exact opposite is the truth. This example affords a pointed illustration of the straits to which forestry advocates are often put in trying to square the direct and necessary consequences of their reasoning with a conventional theory which they are reluctant to oppose.

In the following sentence Mr. Willis repeats that singular inconsistency which can arise only from trying to fit facts to a preconceived theory:

"So retentive is the humus that, while it serves as a sponge to prevent run-off and transmit water to the ground reservoir, it does not give up much to storage, and yields its water-content only slowly to the moderate influences of evaporation in the shade."

The direct inference from this is that the water stored in the forest bed will yield itself up to soak into the ground, but not to run off the surface of the ground. The water will follow the line of least resistance wherever that may be. Under certain conditions more will

Mr. Chittenden.

run off the surface than goes into the ground; under other conditions the reverse will be true; and under still others it will all go up into the air.

Mr. Willis should take this sentence and go out into the woods in a long, flood-producing rain, and see what will become of it; and then go into the forest in the height of a severe drought and see how it will apply to a chance shower that may come along.

The writer will not consider Mr. Willis' remarks regarding the action of forests upon snow-melting further than to cite his real conclusion, which coincides exactly with that of the text:

"Later in the season, the forested parts of such regions sometimes occasion severe floods in consequence of a large body of snow lingering until the warm winds strike it. This effect is undoubtedly unfortunate, but the question may well be asked whether it were better to have the June flood on top of that of April, rather than divided, as they are likely to be in consequence of the presence of the forest."

Concerning this last point, the writer has indicated in the curves of Fig. 1 how much he thinks absence of the forests would advance the crest of the flood. It would probably never amount to more than two or three weeks. There would be no danger of its coming on top of the April rise.

Messrs. Willis and Pinchot both raise the point that second-growth timber, filled, as it generally is, with underbrush of various sorts, is not as effective upon water storage as the virgin forest bed. While the writer does not wish to obtrude his opinions against such eminent authority, he can only say that, from quite extensive observations in a direct practical way, he believes the opposite to be the truth, and he can see no reason, even theoretically, why his view is not correct. Let any one go out into a genuine tract of second-growth timber, compare the tufted ground with that of the forest, observe the effect of showers, and he will find very little to support the above theory. In regard to erosion, there is no question whatever but that the soil under such growths is as well protected, and often better than under the virgin forest.

The following quotation is given from Mr. Willis' reference to the investigation of Professor Glenn, of Nashville, simply to fix the attention of engineers upon the character of the evidence being introduced in this discussion:

"Forty-six creeks and small rivers, the water-sheds of which may be described as timbered rather than cleared, are known, according to observation and local repute, to rise gradually in times of flood, to continue high for several days, and to subside slowly. They carry but little sediment, and they maintain a good volume of water during dry seasons.

"Thirty-eight creeks and small rivers in the same water-sheds, having slopes which may be described as cleared rather than tim-

bered, are known, according to observation and local repute, to rise rapidly in times of flood to extreme flood height, to carry excessive quantities of mud, sand, and gravel, and to fall quickly. In dry seasons they are very low, and the range from lowest to highest stages has increased, and has inflicted much damage in very recent years." Mr. Chittenden.

Note the complete absence of data which would ordinarily be considered necessary to base a conclusion upon—nothing as to relative areas of cleared and wooded land; nothing as to character and extent of cultivation; nothing as to slopes and character of water-shed, and the location of permanent springs; no records of rainfall and none of stream flow; no past records of any kind to compare with the present; nothing but "observation and local repute." The writer will not comment upon this matter further than to animadvert, perhaps rather severely, upon the unscientific character of methods like these, which are so largely resorted to in promoting the cause of forestry. The scientist who permits his researches to become enlisted in the advocacy of a "cause" is treading upon dangerous ground. The moment he departs from the narrow path of declaring the truth, no matter where it strikes, that moment he ceases to be a scientist and becomes a partisan. Less culpable is the use of loose and inaccurate data in one whose business is promotion rather than scientific research; but even with him common sense should be given some authority. Recently the whole country was startled by the news that a distinguished official of the State of New York had found a place near the source of the Hudson River where the water of that stream was only 2 in. deep! This was the only fact stated; nothing of where the shallow part was found, nor whether it was upon some broad gravel bar where the stream spread out in a thin sheet, nor whether the figure was a measurement or a guess. Only one other thing was certain, and that was that the destruction of forests was the cause of the low water, although this was after one of the most prolonged droughts that the country had ever seen. Lewis and Clark record that after their long journey of many months and several thousand miles up the Missouri River they at last came to a point where the stream was so small that a man could bestride it. Their report contains no hint that this was due to a lack of forests.

The official above referred to also declared that New York City's new water supply would be ruined if certain forests in the Catskills were cut off. While it may be undesirable to permit those forests to be cut, it would be utterly impossible to prove that, if they were cut and replaced by a good turf with grass or shrubbery, the supply from the water-shed would suffer in the smallest degree, either in quantity or quality. Yet this alarmist report was taken up by the press quite seriously, and spread all over the country.

In reference to Mr. Willis' closing remarks concerning erosion

Mr. Chittenden.

as a result of forest cutting, the writer maintains that these effects are generally confounded with those of cultivation, and evils are charged to the removal of trees for which it is in no wise responsible. He will endeavor to show later that the case of China is no exception.

Dr. Smith makes what seems to the writer an essentially sound statement of the function of the forest mulch when he says that it "acts as a temporary reservoir of limited capacity, but it contributes its stored waters downward as well as outward." This is the writer's position exactly, although he may differ from Dr. Smith as to the relative quantities that go outward and downward under varying conditions. The writer, however, dissents in the general case from the further view that cultivated land does not store and transmit precipitation to the ground as effectively as does a forest soil otherwise similarly conditioned.

Dr. Smith's reference to his observations on Table Mountain should be read in the light of his frequent encounter of drifts. It is precisely that formation, whether in or out of the forest, that prolongs run-off far into the summer. To make his experience applicable to the writer's argument, he should have mentioned what he found in those areas of the forest, by far the greater portion, where drifts did not take place. Mr. Collingwood's remark: "In the woods * * * near Elmira, N. Y., the drifts remained unmelted long after every bit of snow had disappeared from the cultivated portions of the valley," is subject to the same criticism.

Dr. Smith and Mr. Willis both take exception to the writer's citation of White River, Washington, as an example of a torrential stream coming from a perfectly protected water-shed. Both attribute its character in this respect to the glacier at its head, Mr. Willis deploring the writer's "unfortunate" lack of acquaintance "with the real character of the river." Concerning this last matter, it may be said that after the great flood of 1906 the writer was engaged by King and Pierce Counties, Washington, to investigate the flood problem of the Cedar, Green, White, and Puyallup Rivers, and made a special study of the situation on White River. He states most positively that the glaciers are an entirely negligible quantity in producing the floods of that stream.

In the first place, at the season of the year considered, precipitation on the glacier is almost exclusively snow, a part of the accumulation that goes on every winter. It is not believed that there is any large amount of surface melting at that season, and what there is tends more to compact the body of snow beneath it than to run off into the streams. It is in midsummer that the flow from the glaciers is greatly accentuated. It is then that it bears the milky appearance from

which this stream is said to derive its name; but its character as a "bad" river comes not at all from this regular annual glacier run-off, but from the great freshets that originate almost entirely below the glaciers. Mr. Chittenden.

In the second place, the glacial area on the White River water-shed is barely 2% of the total area. Even if it contributed its full quota, based upon areas, and it could do no more, its influence would still be quite insignificant. The same consideration is equally true of the Skagit River, in which the proportion of glacial area must be even smaller.

Finally, the simple fact is that there was no apparent difference in the run-off of those water-sheds in the flood of 1906. While the much steeper slope of the White gave its flow a more torrential character, there was nothing to indicate that the yield per square mile from the water-shed was greater than from the Green. The overflow of Green River was extreme, and the destruction wrought was great. Even the Cedar River, a small stream, was quite as destructive as the White in proportion to its area of water-shed, washing away railroads and doing other extensive damage.

As to the statement that the floods of White River get out of the way before those of the Green and Cedar come down, it is wholly erroneous in any general flood. Possibly a storm might affect the White River water-shed in some case in advance of the others, and this, with the steeper slope of that stream, might bring its waters down somewhat in advance, but this was certainly not the case in the flood of 1906, and in all the writer's investigations he never before heard the idea suggested. The water-sheds of all these streams are within 24 hours (by river flow) of the lower valley, and this fact itself makes it impossible that the floods of one should escape those of the others, except in a very slight degree.

The writer would invite particular attention to Mr. Kuichling's statement of the difficulties of treating these subjects with scientific precision, on account of the lack of data, and of the necessity of acquiring "a much larger volume of accurate observations" before these questions can be definitely settled.

Mr. Labelle, in the same vein, touches upon an important matter when, in reference to the studies of the Forestry Service now in progress for determining the various relations of forests to rainfall and run-off, he says "The Engineering Profession can never have full confidence in the results of work of this kind done by the Forestry Service alone." The reason for this is that that service has a "cause" to promote, and it is human nature to bend everything toward the side of such a cause. The writer has found in his studies that in nine

Mr. Chittenden.

cases out of ten he can write out beforehand the answers which a forestry enthusiast will make to a given set of questions pertaining to the influence of forests on stream flow, and in some of his researches into foreign conditions he had to reiterate his request that his inquiries be referred, not to the forestry organizations, but to hydraulic engineers familiar with practical river problems. If the Government is wise, and wishes the results of any investigation that it may make of this question to command the confidence of the trained thought of the country, it will place it in the hands of a body of which a majority at least belongs to the Engineering Profession and are not directly or indirectly so connected with the forestry service as to be biased in their deductions. The engineer has no cause to promote. His business is to direct the powers and resources of Nature to the benefit of Mankind. He has no "preconceived ideas" that are likely to interfere with his findings. If the planting of forests can be made of practical value in regulating our rivers, he will welcome that fact; if not, he will not hesitate to say so. Therefore any comprehensive study of this question should be placed in the hands of the Engineering Profession if its results are to command the confidence of that Profession.

The references to China, by Messrs. Labelle and Willis, suggest a feature of this subject which the writer is inclined to develop somewhat. Although perfectly cognizant of the part which historic allusions to Syria, Spain, China, and other countries have been made to serve in this forestry propaganda, the whole argument seemed so entirely unworthy of serious weight that he made no reference to it in his paper. It has, however, been prominently brought to the front of late, and even carried into this discussion, and it is, perhaps, just as well to give it brief consideration here.

The following, from *Conservation* (*Forestry and Irrigation*), is a typical statement of the case:

"Before the forests of Lebanon were destroyed, Palestine supported in affluence ten millions of people. The mountains have long been denuded. Forbidding slopes, barren and ugly, rear their weird forms sharply above the dismal and desolate valleys. Scarcely four hundred thousand remain in all the region, and most of those are in wretched, hopeless poverty. Syria, once maintaining a multitude of prosperous towns and cities * * * is at present a scene of irreparable ruin. The destruction of Syrian forests, begun 2650 B. C. [note the minuteness of this historic detail], followed by the disappearance of her soil and the decay of her industries, would alone have produced this result."

Where is there even a shred of evidence to support any such sweeping statement as this? Anyone who has ever read the Bible knows that it abounds in proof that the general climate of Syria and contiguous countries was essentially the same 4 000 years ago that it is

to-day. When the children of Israel left Egypt and traveled around the Arabian peninsula on their way to the Promised Land, they nowhere lost their way in a primeval forest. They were in a "desert" or "wilderness" (synonymous terms in the Bible) most of the way. References to the "desert" everywhere abound in the Bible. As soon as one was a stone's throw away from the towns or cultivated tracts he was in a desert or the wilderness. The folk-lore of the Scripture makes repeated references to trees growing by watercourses, which have no meaning to a person familiar only with a country where rain falls abundantly and trees grow everywhere, but are full of meaning to him who has lived in an arid country where trees grow only along watercourses.* Mr. Chittenden.

The celebrated Forest of Lebanon was not in Palestine, but occupied the valley of the Leontes River and the neighboring mountains to the north; a tract possibly 100 miles long by 20 wide. Its area did not exceed 2% of the area of Syria. Its influence upon the climate of that country was and is due almost entirely to its mountainous character. The famous cedars grew in groves, not densely continuous, and covered only a portion of its area. That the removal of those forests has not by any means ruined the country, even where they once used to thrive, is evidenced by the fact that agriculture on a considerable scale flourishes there, the streams are fed by perennial snows, and the region maintains a population estimated at from 260 000 to 400 000.†

Professor Albrecht Socin, of the University of Tübingen, a very learned authority upon these subjects, says:

"Palestine is a country of strong contrasts. Of course it was the same in antiquity; climate, rainfall, fertility, and productiveness cannot have seriously altered. Even if we suppose that there was a somewhat richer clothing of wood and trees in the central districts of the country, yet on the whole the general appearance must have been much the same as at present. To the stranger from the steppes arriving at a favorable season of the year, Palestine may still give the impression of a land flowing with milk and honey. The number of cisterns and reservoirs is proof enough that it was not better supplied with water in ancient times."

The same authority says, of the ancient population of Palestine:

"The number, two and one-half to three millions, may indeed be taken as the maximum; the population can hardly ever have been more than four times its present strength, which is estimated at about 650 000 souls."

* For example, Jeremiah xvii, 8: "For he shall be as a tree planted by the waters, and that spreadeth out her roots by the river, and shall not see when heat cometh, but her leaf shall be green," etc.

† Objects that loom big through the vistas of time often dwindle to pigmy proportions when seen from near by. The draft upon the Forests of Lebanon for the building of Solomon's Temple, an event of such vast moment in its day, and employing an army of men large enough, apparently, to sweep the whole country free of trees, did not amount to more lumber than a well-equipped modern saw-mill would cut out in a single day.

Mr. Chittenden.

Another authority says: "Under good government and with thorough cultivation, several times the number [of the present inhabitants] could be easily supported;" and Professor Socin says of Mesopotamia, that now abandoned home of former millions, that a restoration of the ancient canals would restore the former productiveness of that region.

It is not too much to say that, from any point of view, it is doing violence to common sense to attribute to the removal of forests (where they have been removed) the conditions now prevailing in those countries. Those conditions are due to the character of the inhabitants and to a demoralizing and despotic government, which suppresses true liberty of trade and industry, and makes even human life unsafe. Such a people and such institutions would make a desert of Eden in any part of the world. Sweep away the inhabitants and their government and replace them with the free institutions and virile life of the Anglo-Saxon or German people, and the face of Nature will undergo an immediate change whether a tree is planted or not.

So, likewise, the claim that the present climatic and physical conditions of Spain and Northern Africa are due to the removal of forests that once existed there cannot be supported by evidence that would be considered satisfactory upon any other subject. We know little if anything of a definite character concerning the extent of the forests alleged to have flourished there. We know nothing of the rainfall and stream flow, as they were before the period of the supposed removal of those forests. If there is a difference, we do not know that it is even remotely traceable to the removal of forests. All we know is that conditions of stream flow in some districts are not such as might be desired, and that forests are not as extensive as might be desired; but there is absolutely no warrant for connecting these conditions in the relation of effect and cause.

The Nile has apparently not changed its characteristics in the long period of recorded history in that valley, and certainly not from any traceable relation to a removal of forests on its water-shed. Among the replies received in response to a circular letter of August 27th, 1908, by the Forestry Bureau, inviting answers to certain questions in regard to the effect of deforestation upon stream flow, Mr. Oscar T. Crosby, formerly an officer of the Army, submitted the results of his quite extensive observations upon the Blue Nile in Abyssinia. Judging from the presence of a few flourishing groves, and the fact that the plateau would evidently support trees, he assumed that forests probably existed there prior to the occupancy of the plateau by Man, and that they had since been removed for his convenience and use. But as to the effect of their absence upon the flow of the river he thought it quite negative, and summed up his conclusions as follows:

"First. The Blue Nile presents a case in which deforestation of the drainage area has taken place, followed by a covering of the soil

with various prairie grasses and to some small extent with agricultural crops. Mr. Chittenden.

"Second. In spite of such deforestation, and in spite of a strongly marked seasonal rainfall, and in spite of the narrow bed in which the river flows, there is no indication of a more strongly marked fluctuation in the flow of the river than was the case before deforestation.

"Third. The said variation in flow is not greater than that met with in streams whose drainage areas are still fairly well covered with native growths or with luxuriant agricultural crops."

But the *pièce de résistance* in this class of argument is China. Now, China proves several things in regard to forestry, but the beneficial effect of forests upon stream flow is not one of them. Evidence that forests have prevailed to any great extent anywhere in China proper during the past 2 000 or 3 000 years is wholly fragmentary and illusory. In the most general terms possible, Marco Polo mentions that there were forests upon the hills in Shansi and Shensi in his time (13th century), but there is no reference to the extent or character of the timber. Anyone who will read the records of early overland journeys across the plains in this country will find equally strong references to woods, where nothing but the scanty covering of the Black Hills (as the name formerly applied to the mountains in Eastern Wyoming) and other similar tracts is meant. In fact, from the similarity of climate, it is reasonable to suppose that this was the character of the forest. Dense woods do not flourish in a dry climate, and the timber was probably similar to that which crowns the hills in the western portion of our own country. A recent traveler in China, and a practical observer, says of its hills:

"On the whole they remind one of the hills of New Mexico, Colorado, and Arizona, and, so far as one can now see, were never covered with trees and luxuriant vegetation. This is doubtless due in part, if not entirely, to the extreme aridity of the climate."

Marco Polo's reference would fit with our western forests better than with the luxuriant growth of humid climates, and some future historian of our own country would be just as much warranted in concluding, from early references to trees in the arid regions of the Far West, that that country was naturally richly wooded, as we are from Marco Polo's scanty allusions that China once supported heavy forests anywhere out of reach of the rainfalls that come in from the ocean.

But, whatever the character of the original forest growth of China, and whenever it was cut off, one thing stands out clear and indisputable, and that is that the character of her great rivers is essentially the same that it has ever been. This is notably true of the Hoang Ho, or Yellow River, which stands pre-eminent among the rivers of the globe as a stream of destructive floods. In physical characteristics, it is an exaggerated case of the Missouri River. Flowing from an arid or semi-arid region, its actual discharge per unit area of water-

Mr. Chittenden.

shed is small, but it flows for upwards of 1 000 miles through a region of what geologists term loess, a soft formation which is readily washed into the river by rain or blown in by the wind, and contributes to the river a quantity of sediment apparently far in excess of that which comes from the Bad Lands of the Missouri. The Great Plain of China, as it is called, extending for 800 miles up and down the coast and 500 miles into the interior, is the delta of this great river whose tawny flood has given its name to the sea into which it flows. The great burden of sediment which it carries is out of proportion to the volume of discharge, and its bed fills up like that of the Platte River, in Nebraska, and overflows readily into the surrounding country. Like all such streams, its immediate borders are higher than the ground farther back, and the water once out of the banks spreads over the country in all directions. Owing to the great density of population in the plain and the impossibility of finding high ground for refuge, escape from these floods is very difficult, and they are therefore enormously destructive of human life. It is this fact that makes the Hoang Ho such a problem to the inhabitants of the Great Plain and even to China herself.

Now the habits of the Hoang Ho River have been the same from the very dawn of Chinese history. In the will of one of her great Emperors is the statement that it had been "from the remotest ages China's sorrow." Wex, in the treatise already alluded to, quotes at length from a voluminous Chinese work, in part translated into German in 1858, on the management of Chinese waterways, in which the diking of the Hoang Ho is traced back 2 500 years, B. C. The river has changed its outlet no fewer than eleven times in that period, and the evidence is conclusive that it has been essentially the same stream from the beginning. In the citation above referred to, no mention is made that its floods are worse than they used to be, or that they have been influenced by deforestation, if there has been any. Wex would not have omitted any such evidence if he had found it. He traces the growth of the levee system, by which the overflow of the Hoang Ho was kept under at least partial control. As a result:

"The extensive lowlands, which this water once covered entirely or turned into swamps, have been completely drained, cultivated, and planted with mulberry trees, cotton, sugar cane, rice, and all sorts of grain, and now indisputably belong to the most cultivated and fertile lands."

These agricultural developments were brought into existence without any reference to the forests on the water-shed of the Hoang Ho, and, if they are now undergoing an unfavorable change, it is not in any sense due to the absence of forests. That any such influence has changed or is changing the climate of Northern China is not for a moment to be admitted. That a course of civilization which has come

down through an era of 5 000 years, very unchangeable in its character, each generation doing essentially what its predecessors did, is now, within 50 or 100 years, changing the climate of its country and bringing the Mongol Desert nearer to its doors, is simply unbelievable. These results may be ensuing, but deforestation is not the cause. Mr. Chittenden.

From the best evidence available, it does not appear that the magnitude of the floods of either the Hoang Ho or Yang Tse Kiang, measured in absolute quantities or per square mile of drainage basin, equal those of the Ohio. General James H. Wilson, who inspected the embankments of the Hoang Ho in 1885, considered that the control of that stream was entirely practicable, and that the present overflows are due largely to inefficiency in construction and negligence in maintenance of the levees.

The Hun Ho, which has been referred to as an example of deterioration due to deforestation, being navigable in Marco Polo's time but non-navigable now, is, according to Colonel Yule, the editor of Marco Polo's work, not the stream to which Polo referred at all. But whatever may be the stream to which he did refer, his references are so vague, and the character of navigation so uncertain, that definite conclusions cannot be based upon them. Moreover, if Man is the cause of channel deterioration in the streams of that country, assuming that such has taken place, it is, as the writer has pointed out in the case of our own country, cultivation (his subsequent operations on the soil) which is responsible, and not deforestation. In the Chinese order of life every vestige of vegetation is combed off the hills, and they are left barren and a prey to the elements. It is not trees alone, but grass, brush and growths of every description. The effect of the removal of whatever trees formerly stood there could be nothing to the subsequent denudation of the soil.

If one were to carry this illustration to its limit, he might enlarge upon what Mr. Labelle has pointed out, that the one fact which the case of China proves beyond peradventure is that a great civilization and a dense population can subsist with almost no reliance upon forests, for the Chinese make very little use of wood. Here is the oldest civilization in the world, the most homogeneous people, the densest population. It is not a race of invalids, either. General Wilson says of them as he saw them in 1885:

"After seeing the Chinese people under all conditions of life, and in many remote and widely separated parts of the empire, I am compelled to say that they seem to me to be remarkably sturdy, robust, and healthy, and to be especially free from consumption and all other forms of constitutional disease." And again, " the Chinese race is certainly strong and vigorous, and shows no sign whatever of decay."

Although a large part of China proper is too mountainous to be thickly inhabited, yet the average density of population per square

Mr. Chittenden.

mile is over 300, while in the Province of Kwang Su it exceeds 800. Doubtless there are extensive areas in the Great Plain where it exceeds 1 000. The population of Rhode Island is about 450, and of Belgium about 590 per sq. mile, these two areas representing, probably, the maximum densities of population in America and Europe.

Now look at the opposite picture. When Columbus crossed the Atlantic, the continent of North America from the ocean to and beyond the Mississippi was covered with the largest unbroken primeval forest then existing upon the globe. The country was inhabited, and the race found here had been here long enough for the forces of procreation and the restraints of environment to have found their equilibrium. There is no evidence that the population was increasing. While the estimates are uncertain, none of them give a population for the country as a whole exceeding one inhabitant to 7 to 10 sq. miles. This is what an all-forest country can support. The first thing our ancestors did on coming to these shores was to destroy the forests, and the greatest single work ever done on this continent has been the removal of the forest and the clearing of the land for cultivation. Its cost in money and labor has amounted to many billions of dollars.

Lest this illustration be construed as an argument against the usefulness of forests, Germany may be cited as a high type of progressive civilization, with a population of about 300 per sq. mile, and 25% of its area devoted to forest. Possibly that country presents the equilibrium between the forest and cultivated land that comes nearest an ideal condition. To us it seems that China might introduce wood into her economic life with advantage to her people, and that the planting of trees would be of great benefit. It would not simplify in the least degree the problem of her rivers, but if a portion of her territory could be devoted to forests, and if transportation facilities could be so developed that the product could be brought to the people, it would seem that their condition would be improved thereby.

The history of irrigation reveals the fact that in all the countries here considered irrigation was practiced in very ancient times. Remains of canals, aqueducts, etc., are indisputable proof of this fact, and therefore of the aridity of the climate where such measures were necessary. In our own country the remains of ancient ditches have been found in Arizona, yet no one would think of attributing their abandonment, nor the disappearance of the people who built and used them, to the destruction of forests. So likewise it is wholly unjustifiable to assume that the climate of these historic countries has changed, if at all, through any change that Man has wrought in the forests which are supposed to have existed there.

The instability of industrial and commercial conditions is a marked characteristic of human history, and quite as much so of the present as of the past. Cities grow up and play a great part in the

world's activities, and their foundations seem immovable. But a turn of the wheel—a political upheaval, a decisive battle, a change in commercial or industrial relations and even slow-moving forces indiscernible at the time—leads to their gradual decline and the transfer of their greatness to other localities. In but few instances do we know the actual causes of these changes, though doubtless diligent research would disclose them. Our forestry friends, unhappily, do not take kindly to this sort of research, but prefer the short-cut of attributing all such decadence to the removal of forests. Mr. Chittenden.

The rivers of India and those of the comparatively new regions of Australia and South America furnish additional examples of the fact that the presence or absence of forests, *per se*, has little influence upon the character of the world's great rivers. Conditions that would improve these rivers, such as more copious rainfall, would also produce forests, and *vice versa*. The clearing of land in humid climates, like those of Central Europe, England, and the United States, has never produced a desert. Why, then, assume that desert conditions in the arid regions of the earth have been produced by this cause? Such an assumption is a reversal of cause and effect—a placing of "the cart before the horse." The cheerful readiness with which the genuine forestry enthusiast pursues this course, when common-sense considerations are all against it, is one of the singular phenomena connected with this subject.

While Colonel Pickett's observations of snow phenomena in the Rocky Mountains generally accord with the writer's, it is difficult to understand upon what basis he makes his deductions. Has he never stopped to ask why it is that the "June rise" is a forest flood? Has he ever seen such rise from the open country unless in some exceptional case? If forests moderate floods, why is it that the regular annual flood comes from the forests?

Colonel Pickett is clearly wrong in saying that crust forms more solidly in the forest than in the open. Just as dew and frost gather more abundantly in the open because of freer radiation, so the crusts on the drifts in the open are thicker than those in the forest. The Colonel further errs in saying that this crust always forms in the forest. It is just the opposite fact that causes the danger from forest snows. These snows are held until the genuine warm weather of summer comes. Then it invariably happens that there will come periods when the temperature does not fall below freezing at night and when rains continue for days at a time. These are the combinations that rush the waters headlong into the streams.

Colonel Pickett refers to his taking cattle to the high open country for grazing before snow has gone in the forest. But he omits to men-

Mr. Chittenden.

tion the drifts that he certainly found in the ravines and behind the shoulders of the hills. Has he not seen these drifts, within the altitudes at which timber grows, last until August? Has he ever seen snow in the forest at that late date, unless in some special situation where it has drifted or has been protected by a northern slope?

Colonel Pickett's reference to what he saw in the valley of Heart River, North Dokota, has a significance quite other than that which he has attached to it. These prairies are a living evidence of the efficiency of snow drifts in preventing floods. The deforested area of this water-shed is very great, compared with the small extent of the forested areas at the sources, yet the "April rise,"which marks the disappearance of the prairie snows and the break-up of the ice in the river, is nearly always inferior both in volume and duration to the "June rise." Why should this be so? Because the snow that falls in the open country of the water-shed is nearly all blown into sheltered corners, or behind clumps of brush, and, in these later years, fences. The early spring sun in that clear atmosphere carries off the thin covering outside the drifts, and when the warm weather comes that brings the "April rise" the snow surface left to act upon is an exceedingly small proportion of the entire area.

Colonel Pickett's supposed benefits of mountain forests to the floods of the Lower Mississippi seem to the writer wholly visionary. If he will take any "June rise" that he may select, differentiate the portion that comes from the forests, arrive at any estimate that he may consider fair of the difference in the volume of this rise due to any practicable change in forest areas, then trace this difference 3 000 miles to the mouth of the Ohio, he will have hard work to convince himself that it could amount to 10 000 cu. ft. per sec., a quantity that would be wholly lost in any great flood of the lower river. According to the writer's view, however, the difference produced by the reduction of forest area would be beneficial. The flood crest would come but very little earlier (see Fig. 1), and it would be lower. In fact, so far as the effect upon the run-off from snow-melting is concerned, one could look with complacency upon the entire removal of the mountain forests.

Colonel Pickett's suggestion that trees be planted along the upper limit of their present zone of growth is open to the criticism that the timber itself would be of no economic value because of its inaccessibility, and, so far as it might interfere with snow drifting in winter, it would be a positive detriment to stream-flow. The writer, however, has never gone to the length of suggesting a removal of our mountain forests in the arid regions, though the idea has been distinctly put forth by three contributors to this discussion. The writer assumes that the economic value of these forests for timber will outweigh their drawbacks in the distribution of snowfall. Then there is the uncertain effect upon precipitation, and until this relation is

thoroughly understood it would be unwise to remove the forests. In the region of the Yellowstone Park, however, of which 85% is covered with forest, the writer has long felt that a removal of say one-third of the present timber, selecting for this purpose the areas of undesirable lodge-pole pine, would promote every interest which that region serves. It would give wider pasturage for the game, it would give more frequent landscape views where now the tourist travels for hours at a time through monotonous forest, it would give a better distribution of snowfall and promote uniformity of stream flow, and it would be of great value in preventing the extensive range of forest fires. Mr. Chittenden.

Concerning Mr. Leighton's entire argument, the writer cannot forbear observing that if he had devoted a small fraction of the mental energy in trying to understand what the writer actually said that he has in attempting to disprove what he did not say, the greater part of his contribution would have been unnecessary. Most of his arguments which the writer cares to consider, have already been noticed. A few remaining points will here be taken up.

Mr. Leighton's citation of Dr. McGee's opinions is simply a mass of misstatement which admits of no reply except a flat denial. Nowhere in his paper has the writer even remotely hinted that "there is no connection between rivers considered with respect to improvement and the sediment they carry"; or "that water is the object matter of the engineering art and sediment the object matter of scientific farming"; or that the sediment carried by a river is at one and the same time through and local freight. Until he knows more fully what Dr. McGee actually said, he will assume that Mr. Leighton has not quoted him correctly.

It is to be hoped, also, that Mr. Leighton misquotes when he says that Dr. McGee "testifies that the Missouri is still a clear river after passing the Montana Bad Lands." If Dr. McGee ever saw the Missouri River clear at any point below where it leaves the foot-hills of the mountains, he is the only person who ever saw it so, and the occasion was the only one on which it ever occurred. It was assuredly one of Mr. Leighton's "freaks." Below the point where the river emerges from the foot-hills and enters the alluvial bottoms it is never clear. The only time that it even approaches clearness is in the dead of winter, when the water-shed is locked in ice. In the winter of 1905 there was a prolonged period of very low temperature in the Upper Missouri Basin, the thermometer remaining well below zero most of the time for more than six weeks. The small streams all over the water-shed were frozen up tight. Curious to know to what extent the discharge of the river would shrink under these conditions, the writer caused

Mr. Chittenden.

a measurement to be made at Sioux City. The result was 6 920 cu, ft. per sec., or about $\frac{1}{50}$ cu. ft. per sec. per sq. mile. The water, though much clearer than ever seen without the ice covering, was still so turbid that it could not properly be called transparent. An interesting feature was the appearance of the underside of the blocks of ice removed to admit the current meter. Glassy as is the ice formed on still-frozen water, it was nothing to the polished smoothness of the nether surfaces of these cakes resulting from the continual sandpapering by the fine sediment in the water.

Concerning the Upper Mississippi reservoir system, the writer reiterates his statement that he considers it of great public importance, and is an advocate of its extension; but that does not blind him to the fact that its value for industrial use far exceeds in importance, under present conditions, its value for either flood protection or navigation, or both.

Mr. Leighton's explanation of the flood of 1905 on the Upper Mississippi is quite unnecessary. The writer's point is very simple, viz., that a stream emerging from a natural lake never rises as high or falls as low in discharge as it would if the lake were not there. If, therefore, the lake be dammed up at its outlet, but cannot be allowed to rise beyond a certain elevation, and if that elevation is once reached, any subsequent storm finding the lake in that condition must be run out as fast as it comes in. If it is a heavy, flood-producing storm, it may and probably will cause a greater outflow than it would in the natural condition of lake and river. To that extent, it may enhance flood conditions in the valley below.

In like manner, the lengthy discussion of the writer's remarks about wave propagation down the Ohio River does not affect in the least the simple point involved, viz., that if a reservoir cuts off the peak of a flood wave on any stream, the resulting diminution of discharge at any point below will never be as great as at the reservoir, because of the flattening out and lengthening of a wave as it moves down stream. The writer thought that Mr. Leighton had calculated the full reservoir effect at all points below, and is still uninformed that he did not. If he did, his deductions were to some degree in error.

Mr. Pinchot's lengthy explanation of his illustration before the House Committee on Judiciary is quite irrelevant because it does not touch the point of the writer's criticism, viz., that he had used an illustration to explain to a responsible body of public men the beneficial influence of forests upon stream flow, and in so doing omitted to apply it to the conditions of flood and drought, the conditions of paramount importance, and confined it to medium conditions, midsummer showers, so to speak. His illustration, therefore, was incomplete and misleading, and his explanation leaves the matter in no better shape than it was before.

Mr. Chittenden.

Mr. Pinchot's remarks upon snow-melting are explainable only through lack of observation. Does he really mean to say that the forest temperature in fall, winter, or spring is lower than in the open? The reverse is generally the case. The more rapid melting in the open is due to the direct action of the sun upon the thin snows. This melting often takes place even when, in the shadow of a tree or rock, freezing is going on. It is not the warmth of the general atmosphere, but the direct action of the sun that melts snow in the open when it is not melting in the forest. Mr. Pinchot adds: "If the melting went on as fast in the forest as it does in the open, the discharge of the water would be greater, * * * and floods would thereby be intensified." This is precisely what happens when the forest melting begins. The forest snows then melt a great deal faster than in the open, and do materially intensify the floods. This is why our mountain floods in the spring, the "June rise," come from the forests. Again: "The only condition under which the melting, for like conditions, is anything like as fast as in the open is during a warm rain." Does a warm rain prevail in a cold atmosphere? And, when the rain stops, does it at once become cold? It is not the Chinook wind in the intra-mountain regions that does the melting of which the writer speaks. It is the natural warmth of summer. The forests hold the snows until genuine summer conditions arrive, with flowers blossoming wherever there is a bare foot of ground, and then yield up their water with a rush. Nearly always at such times, rains develop which accelerate the melting, and contribute their own water to the flood. The net result is to add together the precipitation of several storms.

Mr. Pinchot says that the drifts melt as fast as the shallow snows of the forest. As a matter of fact, this is not so. The heavy, solid drifts, like a mass of ice, melt much more slowly. But admitting for argument's sake that it were so, it is entirely foreign to the point which the writer brought out, viz., that the area exposed in the drift is but a small fraction of the area exposed in the forest for a like amount of snow. He would refer again to his illustration of a cubic yard of snow situated so that only 1 sq. ft. is exposed, and again so that 27 sq. ft. are exposed.

Mr. Pinchot questions the writer's assumption that, of an 18-in. snowfall, 12 in. might be stopped in the dense forests of the Pacific Coast before it reaches the ground. Very well. The writer will accept any proportion that Mr. Pinchot thinks more nearly correct. The principle involved does not depend upon absolute quantities; but, as a matter of fact, more than a foot of snow is often held by these forests, and anyone who has passed through the snow-shed district of the Southern Pacific Railroad in the Sierra Nevada in winter will not doubt that there is an average of a foot of snow on the trees. Mr. Pinchot's attention is invited to the photographs shown on Plate XLVII, taken while this writing was in progress, after a snowfall of

Mr. Chittenden.

about 8 in. The trees are possibly from 15 to 30 ft. high. When it is considered that in the native forest the trees are often 200 ft. high, and so thick that their tops everywhere interlace, and that there are trees of all heights and sizes, with dense undergrowth extending from the ground up to heights of 20 ft. or more, he will readily admit that the snow will find difficulty in reaching the ground, and that such extensive shelter will readily catch and hold temporarily, at least, a foot of snow.

But does Mr. Pinchot think it quite fair to pass from this simple illustration of a single storm to a general proposition of "two-thirds of the snow on the branches and one-third on the ground"? Does he really fancy that the writer believes that, of a winter snowfall in these mountains of, say 9 ft., 6 ft. remains on the trees?

To go into the elementary principles, the ability of snow to cling to any object depends very much upon its quantity, its condition, and the state of the wind. Snow in large flakes, and damp and sticky, such as is common in many of the storms of this region, will cling to almost anything, and the degree to which it will pile up on slender supports in the absence of wind is extraordinary. On the other hand, when the temperature is well below freezing and the snow is dry and fine it will slip from any inclined surface or through a mesh of underbrush as fine, dry sand slips through the fingers. If such snow falls, as is nearly always the case, under the influence of the wind, which shakes such movable objects as tree tops, almost all of it will sift through to the ground. Moreover, as to proportions on the trees and ground, a great deal depends upon quantity. A much larger percentage of a 2-in. snowfall will cling to the trees than of a 20-in. fall, other things being equal.

Both Mr. Pinchot and Mr. Leighton have apparently derived much comfort from the writer's comparison of the American River and Puta Creek water-sheds, in California, and both have referred to it as an "unfortunate" illustration. Let us see on which side of the question the misfortune of that illustration lies. The writer presents a map, Fig. 17, of the two water-sheds, prepared after he had read the report of Mr. Pinchot's remarks and before he had seen his map, Fig. 16. A careful comparison of these two maps is invited, with particular attention to the location of the gauging stations, the outline of the Sacramento flood plain, and the direction of the wind as shown on the writer's map. Mr. Pinchot places Guinda (71) on the Puta Creek water-shed, but, unless all the maps which the writer has consulted are wrong, it is on Cache Creek, quite outside the Puta Creek water-shed. The writer supposed that Calistoga (76) was within the water-shed, but it appears to be just outside, though practically on the border. There is a discrepancy in the position of Tamarack on the American River water-shed, but it is immaterial.

Mr. Chittenden.

WATER-SHEDS OF AMERICAN RIVER AND PUTA CREEK, CALIFORNIA, WITH RAINFALL AND GAUGING STATIONS, FLOOD OF MARCH, 1907.

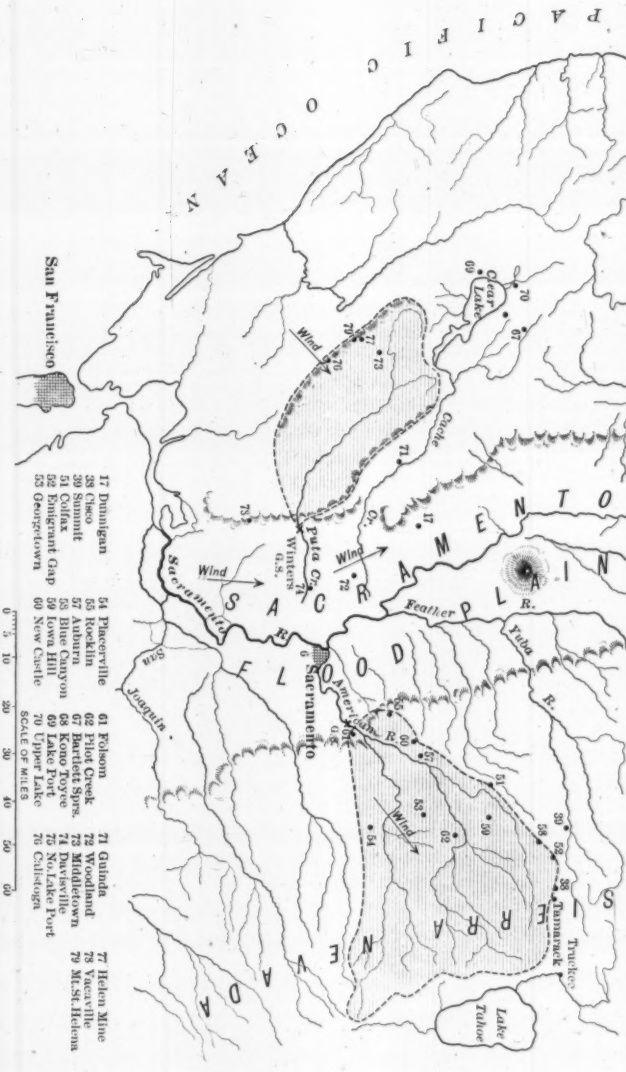


Fig. 17.

Mr. Chittenden.

The writer based his findings solely on data found in the paper by Messrs. Clapp, Murphy, and Martin.* He has since examined the Weather Bureau records, but finds nothing to modify these data, while they confirm the writer's views as to the course of the storms that produced those very heavy run-offs. As to the American River water-shed, Mr. Pinchot's figures and the writer's practically agree, although Mr. Pinchot has added several stations outside the water-shed, not used by the writer. On the Puta Creek water-shed, of the eight stations† used by Mr. Pinchot—(76), (74), (17), (71), (77), (6), (78), and (72)—six—note carefully the number and location—are outside the water-shed, not including Calistoga. The use of so large an element from the outside would, in any case, be questionable; in the case under consideration, when the conditions are understood, it is indefensible. All these outside stations lie in the Sacramento flood plain except Guinda, which is a short distance in the hills. The storm conditions on this plain are entirely different from those in the valley of Puta Creek. That valley has always been noted for heavy rainfalls and enormous run-off. Messrs. Clapp, Murphy, and Martin say that "in the region about Clear Lake and Mount St. Helena, in the Lower Sacramento Basin, the precipitation is remarkably heavy, and occurs almost entirely as rain." The storms sweep in from the Pacific, break over the hills directly upon this valley, and drop the bulk of their burden in passing. The intensified character of these storms is thoroughly understood locally, and must be taken into account in any rational determination of their effects.

The storms in the Sacramento plain are entirely different. Sweeping up from the south, their precipitation is very much lighter than on the hills on either side. This is well shown in the records of this storm. Taking all the stations in the plain from Chico to Suisun, the maximum precipitation for the 10-day period is less than 6 in. in all but one or two instances. The use of these stations in any way in determining the precipitation on the Puta Creek water-shed is inexcusable, much less the assignment of 75% weight to them. A railroad engineer who would estimate in this way the flood flow of Puta Creek, in the absence of discharge measurements, and provide flood capacity on that basis under a bridge that he might be called upon to build, would be guilty of gross professional malpractice. The writer took the only records he had which directly covered the case, but he did not rely on them alone. At many of the stations, Messrs. Clapp, Murphy, and Martin gave 1904 flood readings, and there is a close correspondence running through all the records, between the 1904 and

* *Transactions*, Am. Soc. C. E., Vol. LXI, p. 281.

† Mr. Pinchot does not specify the stations used in his determination, but he gives them in a letter to the writer as follows: Calistoga, Davisville, Dunnigan, Guinda, Helen Mine, Sacramento, Vacaville, and Woodland. The numbers on Fig. 17 are the designations used by Messrs. Clapp, Murphy, and Martin.

the 1907 floods. Applying this to the 1904 record at Middletown, which is well inside the water-shed, a precipitation of between 20 and 22 in. is indicated at that point. A similar use of the Mt. St. Helena record would have raised the figure. Mr. Chittenden.

In short, the writer went at the matter in what seemed to him a direct practical way. It was not a question of isohyetal lines at all, but of trying to find out what actually happened; and he believes that engineers will agree with him, on the basis of the data presented, that the precipitation on those two water-sheds for the period in question was about in the proportion of 20 in. on Puta Creek to 15 in. on American River. Mr. Labelle arrives at a similar result by taking the precipitation for a full month.

But the writer is not at all particular as to the exact figure. He is willing to take in the records of Cache Creek (but not under any circumstances those of the plain). Add in Lakeport and Guinda, and the record will still be about 18 in. Even if it were as small or somewhat smaller than that of the American River, it would not affect the principle involved. For some cause the Sierra water-shed, much larger in area, sent down a much greater percentage of run-off than did Puta Creek. The writer believes this was due in part to the distribution of snow on the Sierra slopes caused by the presence of the forests. In any event, the restraining effect of the forest totally failed to materialize.

And here the writer would like to ask why there should be so much stumbling in this matter. If momentary prejudice is dropped, and the question is looked at from a direct common-sense point of view, is not what happened the most natural thing in the world? Is it possible that the general result should have been other than what it was? Snow always has the effect of transferring the run-off from precipitation to a period subsequent to that on which the precipitation occurred. If the snow melts when additional precipitation is falling, the net result is to bring two storms together, and the run-off must necessarily be greater than that from either storm alone. So far as forests affect the distribution of the snow as to increase the rate of melting, so far they intensify the run-off.

The writer hopes that Messrs. Pinchot and Leighton will not waste any further sympathy upon him on account of this "unfortunate" illustration.

One more "unfortunate" of Mr. Pinchot's is found in Fig. 2, Plate XL, in regard to which it is insinuated that the writer selected a level tract of ground to illustrate the absence of erosion resulting from timber destruction. The writer would not notice this matter at all if it were not that it affords an opporunity to point out one of the chief sins of the forestry propaganda—the use of its photographs. As to the picture in question, it was taken several years ago by an artist from

Mr. Chittenden.

St. Louis, whose fancy was captured by the wierd appearance of the dead standing timber. This, with several other pictures, was given to the writer, and it was the only one in his collection bearing upon the subject in hand when he came to write his paper. If he had had an opportunity to get others, he could have selected hundreds of places of all degrees of slope that would have illustrated his argument just as well. If Mr. Pinchot ever visits that region the writer would ask him to examine the steep slopes of Bunsen Peak and Terrace Mountain, burned over several years ago, and now grown up to grasses and underbrush where hundreds of deer graze during a large portion of every year; and also a steep hillside at Bluff Point, on the shore of Yellowstone Lake, where a former fire has been succeeded by a growth of jack pines so dense that it is impossible to take a horse through it. In fact, in all his travels of many hundreds of miles in burned-over districts in those mountains, the writer has never found any marked erosion resulting from such fires, and does not believe that there is any.

But the course which Mr. Pinchot has quite unjustly ascribed to the writer in this matter is one of constant regular practice by the forestry propaganda. Let anyone examine the photographs illustrating erosion in the Southern Appalachians and other places—bald, rocky knobs, seamed river bluffs, gorges, chasms, and ravines assumed to have resulted from deforestation—and see what exaggerated evidence they constitute. They bear no more resemblance to the normal aspect of cleared land than do the gullied precipices of the Bad Lands to the corn-clad hills of Iowa.

As to the writer's impression, which has so excited Mr. Pinchot's astonishment, that the forest under scientific management is kept free of débris, the writer will say that he has derived it from general reading, from the description of German and French forests, from conversation with those who have inspected those forests, from official publications of the Government,* and finally from correspondence with Mr. Pinchot's bureau itself. It is the writer's understanding that dead timber will not be allowed to accumulate in such forests, that tree tops are cut up for wood or else destroyed as a measure of fire protection, and that the ground will generally be kept clear of the litter that fills the ordinary forest. Possibly the writer's use of the word "rake" gave Mr. Pinchot the impression that he meant that the forest was carefully combed over with a garden rake as one clears up

* For example, in discussing the cause of forest fires, the Secretary of Agriculture says (Senate Document 91, 60th Congress, First Session, p. 29): "All kinds of waste materials left in the woods supply food for the flames, but the leaving of large, unlopped softwood tops on the ground adds enormously to the fury of a brushwood fire and greatly prolongs the length of time that a slash remains a menace to its own and surrounding areas."

And Senate Report 1596, 59th Congress, First Session, p. 7, says: "The dried branches and tops of felled trees also furnish ready material for the spread of the great forest fires which constitute the second agency contributing to the destruction of the forests."

The natural inference from this language is that it is desirable to avoid such accumulations of débris.

leaves from a lawn! He did not mean quite that, but simply that logs and tree tops and dried underbrush will no longer be allowed to accumulate. He would appeal to Mr. Pinchot himself if this is not a correct statement of the case. Mr. Chittenden.

In the forest primeval a large proportion of the mould that covers the ground comes directly from the decay of fallen timber. The accumulation from this source in the forests of the Pacific Coast is enormous. In the Yellowstone forests it is the main source, for the accumulation of leaves and the growth of a mould from the ground itself are very small. It would be interesting if Mr. Pinchot had stated positively whether it is a part of the forestry policy to allow this accumulation to go on. Certainly it is not the practice in foreign countries, judging from all descriptions that the writer has seen. Of course, in our new forest reserves of virgin timber, original conditions will continue for a long while, but they will gradually change as cutting goes on and fresh accumulations of débris are prevented.

From the broad standpoint of forest preservation, it would seem to be exceedingly unwise to let accumulations of dead timber and brush continue. It is the débris of the forest that makes fires so impossible to control, and the control or prevention of such fires is a matter of more vital moment than any beneficial effect of the débris upon the forest itself or upon stream flow can be.

In the light of Mr. Pinchot's definition of the word "waste," the writer's remarks upon that subject may indeed seem not quite to the point. This is another example of change of standpoint in reply to criticism. If waste means simply a loss of opportunity to continue an existing forest, then indeed there has been much waste, and there will be much more. And it is a kind of waste that the writer deplores as much as any one else. He would be very glad if every acre of our woodland, both primeval and cut-over, were under public control.

But this was not the matter to which the writer referred at all, and no one who has read the current literature upon this subject would gather any such idea from it. The constantly reiterated lament is that our forests have been and are being "wantonly" destroyed, "ruthlessly" wasted, "looted" for selfish purposes, and the like. It was to this feature alone that the writer's remarks were directed. Those who cry "waste" rarely consider what they are talking about, or the circumstances attending the alleged destruction. What is waste to-day was not waste at all forty years ago. When "logging bees" were common in New York or Pennsylvania, maple trees, for example, were often an encumbrance to the ground; to-day they are of great value for flooring, piano work, etc. When the pine forests of Michigan were entered, the price of timber was so low that only the best trees could be cut. Now everything that will make a 2 by 4 is utilized for boards, and all other parts of the tree are saved and worked up into

Mr. Chittenden.

charcoal, wood alcohol, or other by-products. In many of our intra-mountain districts the timber that has been cut off served a more useful and necessary purpose at the time in that new country than it ever would again in a thousand years. We must consider the times and circumstances before we accuse our fathers of conspiracy against posterity in a profligate waste of our resources. It was not for them to save trees where their absence was far more valuable than their presence. It is for us, on the other hand, to save them now, for conditions are reversed; but in doing this, as a plain matter of duty to ourselves and justice to posterity, let us not be unjust to our fathers by denouncing them for doing the very things we would have done in their places, and would have done because they were the proper things to do.

The real waste, the lamentable loss, in our native forests has been that resulting from fire. It is difficult to fix the responsibility for this. Some of it has been unavoidable, much accidental, a great deal the result of carelessness, very little of it wanton or malicious. The first and foremost duty of forestry work to-day is to combat and control this agency of destruction.

Quite unnecessarily, Mr. Pinchot reads the writer a lecture to the effect "that each part of the soil must be put to the use in which it will contribute most to the national welfare." The whole tenor of the writer's paper is expressed in this sentence. The simple difference between the writer's point of view and that of his critic is that Mr. Pinchot holds that forests are of all-embracing and universal beneficence, while the writer holds that, like any other product of the soil, they have a strictly limited, though very important, sphere of influence. The writer also holds that their benefits will be greatly enhanced by having them as near as possible to the homes of the people.

The writer will close this review with a reference to the first paragraph in Mr. Pinchot's discussion. He says:

"In discussing the influence of forests on stream flow, it is unlikely that we will ever have a better statement, in certain respects, of the case against the forests than that which Colonel Chittenden has made."

Exception is taken to the word "against." If the writer had some project in hand which he considered of great public importance, and if a friend were to come to him and point out what seemed to be serious defects, while commending the project as a whole, it would scarcely be the part of fairness to charge that friend with hostility to the enterprise. It is precisely this intolerance of criticism which is one of the things most to be criticized in the forestry propaganda. It is noteworthy that no one ventures to utter a word in criticism of any feature of the propaganda without an apology and a careful explanation that he has nothing against the cause of forestry itself. The

writer is as firm a believer in, and as ardent a friend of, legitimate forestry as Mr. Pinchot himself. He has spoken against a spurious forestry only—a forestry which promises where it cannot make good. Fifteen years ago, he accepted without question the current theories, although then urged in a comparatively mild form. It was only by learning through practical experience the erroneous character of some of these theories that he was led to question the general claim in regard to the beneficial effects of forests upon stream flow, and to find upon investigation that it was indeed not well founded. For several years he has had it in mind to present a paper on the subject to this Society, but has desisted for the sole reason that he did not wish, even in appearance, to roll a stone in the pathway of the movement for the preservation of our forests. He should not have prepared the present paper but for the turn which things have taken in the past two years, in which conservatism has been thrown to the winds, the most exaggerated and erroneous notions have been seriously forced upon the public belief, and the drift was unmistakably in the direction of making forestry an adjunct of the improvement of our navigable rivers. In this situation he determined that at least one voice should be raised in protest—one plea made for sanity in dealing with this important subject. As stated at the close of his paper, this decision was taken solely upon his own initiative, and, right or wrong, he alone is responsible for it. If any one supposes that the work was undertaken as a mere holiday recreation, he is mistaken. It is easier to swim with the current than against it, particularly when that current is a veritable Niagara. Nothing but a sense of profound conviction could justify the writer's course, and two circumstances attending the reception of his paper have confirmed his estimate of its timeliness and importance. One is the commendatory references in this discussion and the numerous letters he has received from prominent engineers and others, showing a deep undercurrent of dissatisfaction with the extreme course which our forestry friends are pursuing. The other is the attitude of a few ultra-forestry advocates who have co-operated in this discussion to demolish the writer's argument. It is probably true that no paper has been presented to the Society during its existence that has been denounced in such unmeasured terms from beginning to end as has this paper by the small group of gentlemen referred to. They have found nothing but "fundamental" misconceptions and errors, "unfortunate" illustrations, "curious" doctrines, failure to grasp "elementary principles," "vitiated" reasoning, and finally mistakes so many that Mr. Pinchot plaintively remarks that he is unable to "exhaust" them. The literary form is indeed irreproachable, but a grave peril lurks in this very fact, for the unwary may thereby be "beguiled into acceptance of the author's precepts!" In the words of a gentleman who attended the Louisville Convention of the Ohio

Mr. Chittenden.

Mr. Chittenden.

Valley Improvement Association, the paper is a "dangerous document to the cause because it looks so much like the truth."

It is possible that these gentlemen are beginning to realize that they have slightly over-reached in this matter, and that their very strenuosity amounts to a confession of weakness. Be that as it may, the writer is content to accept the judgment of his professional brethren, in and out of this Society, upon the essential soundness of his seven forestry propositions and of his views of public policy connected therewith.

APPENDIX.

Mr. Chittenden.

The following extracts from writings upon the subject of forests and stream flow are reproduced here because of their historic value in the literature of the subject. In every case they present early, if not original, enunciations of the principles which are now being brought into prominence through the medium of this discussion.

I.

The first extract is from "The Earth as Modified by Human Action," by Mr. G. P. Marsh, first published in 1864, and is reproduced because of its early date and because it is a perfect example of the mixture of wheat and chaff so conspicuous in the present forestry propaganda.

"*General Consequences of the Destruction of the Forests.*

"With the extirpation of the forest, all is changed. At one season the earth parts with its warmth by radiation to an open sky; receives, at another, an immoderate heat from the unobstructed rays of the sun. Hence the climate becomes excessive, and the soil is alternately parched by the fervors of summer, and seared by the rigors of winter. Bleak winds sweep unresisted over its surface, drift away the snow that sheltered it from the frost, and dry up its scanty moisture. The precipitation becomes as irregular as the temperature; the melting snows and vernal rains, no longer absorbed by a loose and bibulous vegetable mould, rush over the frozen surface, and pour down the valley seawards, instead of filling a retentive bed of absorbent earth, and storing up a supply of moisture to feed perennial springs. The soil is bared of its covering of leaves, broken and loosened by the plough, deprived of the fibrous rootlets which held it together, dried and pulverized by sun and wind, and at last taken up by new combinations. The face of the earth is no longer a sponge, but a dust heap, and the floods which the water of the sky pour over it hurry swiftly along its slopes, carrying in suspension vast quantities of earthy particles which increase the abrading power and mechanical force of the current, and, augmented by the sand and gravel of falling banks, fill the beds of the streams, divert them into new channels, and obstruct their outlets. The rivulets, wanting their former regularity of supply and deprived of the protecting shade of the woods, are heated, evaporated, and thus reduced in their summer currents, but swollen to raging torrents in autumn and in spring. From these causes there is a constant degradation of the uplands, and a consequent elevation of the beds of water courses and of lakes, by the deposition of the minerals and vegetable matter carried down by the waters. The channels of great rivers become unnavigable, their estuaries are choked up, and harbors which once sheltered large navies are shoaled by dangerous sand-bars. The earth, stripped of its vegetable glebe, grows less and less productive, and, consequently, less able to protect itself by weaving a new network of roots to bind its particles together, a new carpeting of turf to shield it from wind and sun and scouring rain. Gradually it becomes altogether barren. The washing of the soil from

Mr. Chittenden.

the mountains leaves bare ridges of sterile rock, and the rich organic mould which covered them, now swept down into the dank low grounds, promotes a luxuriance of aquatic vegetation that breeds fever, and more insidious forms of mortal disease, by its decay, and thus the earth is rendered no longer fit for the habitation of man."

Oblivious to the humor of the situation, Marsh adds: "To the general truth of this sad picture there are many exceptions."

II.

The writer regards the following extract from an address by Colonel Thomas P. Roberts before the American Forestry Congress, in September, 1885, as well worth careful study. It is the first rational explanation that has come to his notice of the fact that the low-water flow of our rivers is not less than it used to be, in spite of the generally accepted fact that the little springs and rivulets dry up more than formerly. Colonel Roberts' life-long experience upon the Ohio River, and his inherited fund of information upon the subjects, through his father, the eminent hydraulic engineer, W. Milnor Roberts, whose career was also largely identified with that stream, give his opinion upon the matter, considered in the abstract, more than ordinary weight:

"A river of large drainage area is made up, to be sure, from a multitude of tributaries. Over an area of 20 000 square miles, which is the basin of the Ohio at Pittsburg, there are, even in the seasons of the most protracted droughts, almost daily thunder-storms, of limited area, perhaps, but each deluging in turn one or more of the minor tributary valleys and causing local freshets. No rainfall may be observed at any designated station for two or more weeks at a time; nevertheless the river represents the aggregate of their effect, its low-water discharge being in reality made up of numerous miniature freshets. In other words, I argue that the low-water discharge of the Ohio River is, to a very great extent, maintained by a circulating series of minor freshets.

"A dry-weather spring yielding two gallons of water per minute, making seventy-five barrels daily, would be accounted enough even for the maintenance of a large stock farm. The lowest stage of water ever known upon the upper Ohio was in 1838, when for several days the least discharge of the river was 552 000 gallons per minute, to maintain which it would require the united tribute of 276 000 such springs. For the average season of drought it would require more than 500 000 such springs, to maintain the low-water discharge of the Ohio River. On the other hand, it would require that only ninety-seven square miles of the entire territory of 20 000 square miles be daily visited with a storm yielding for discharge a little over half an inch of rainfall.

"These figures are presented merely to set forth very briefly how great rivers may maintain their low-water discharge. I am persuaded

that if absolutely no rains visited the Ohio valley for several weeks at a time during the summer, the river would literally dry up, for I have no faith that the perennial spring of the forests, supposing the region were a virgin forest, would support the loss due from evaporation in the long, wide, and shallow pools which exist in the main watercourse. Therefore it matters little if the "saw-mill" man's creek has been dried up by the denudation of forests; the river will preserve its constant average. Occasionally the saw-mill creek may burst its banks, rising possibly more suddenly and higher than before its banks were denuded; the river accepts it as just one of those 'ninety-seven square mile floods' due for one day." Mr. Chittenden.

III.

The following article, so far as the writer is aware, is the first ever written in which the injurious effect of forests upon the run-off from snow-melting is set forth; it has reference only to the intra-mountain regions of the Far West. It is by Mr. R. L. Fulton, and was published in *Science*, April 10th, 1896.

"When American enterprise invaded with its iron cavalry the mountain regions of the West, many established theories were put to new tests, and not all sustained themselves. The relations of plant life to water supply, as found on the eastern half of the Continent, had led our fathers to believe that the destruction of forests would invariably and inevitably result in the depletion of adjacent streams and in all consequent evils. So potent is the thick shade which covers the ground in many parts of the Eastern States that no one imagined that conditions existed elsewhere that would produce entirely different results. The building of long lines of railroads [in the Far West] and the opening up of mines have led to the cutting off to the very ground of extensive tracts of timber, and the effect upon local streams has led observing people upon the spot to the conclusion that Nature has surer and wiser methods than she has been given credit for; that she has storage facilities among the mountain tops, capable of resisting the attacks of any human vandals, and that the fountains of her rivers will be preserved to send down precious floods throughout all future time, regardless of what man may say or man may do.

* * * * * * * * * *

"Close observers, after long years of study, have been led to believe that if there is any difference in the flow of streams and the size of springs before and after the trees are cut from above them, the balance is in favor of the open country.

"That water which drops on shaded ground which is thickly overspread with spongy leaves and the air so near the dew point that it cannot absorb much more moisture should be held back, while that coming down on open ground should run off quickly, seems very natural, but in high mountain regions there are peculiar combinations which do much to modify the action of the law. The pine and fir are the only trees found growing at a high altitude in any abundance, and

Mr. Chittenden.

their thin needles do not make the heavy shade when on the tree, nor the thick mat when lying on the ground, that the broad leaves of the oak, beech and maple do. Instead of forming a spongy layer five or six inches thick, they are swept about by the wind and it is not unusual to see the ground bare under the trees and all the needles lodged somewhere in drifts. Even when they lie where they fall the coating is comparatively worthless so far as retaining moisture is concerned. On the other hand the foliage on this class of trees being as heavy in winter as in summer, the branches catch an immense amount of falling snow and hold it up in mid air for both sun and wind to work upon, and only those who have had experience of the absorbing power of the dry mountain air can form any idea of the loss from that source. Such as is melted falls upon that beneath, and breaking the surface sets in operation forces which are always ready to attack such substances. The theory that the shade protects the moisture laden soil means but little in such places. The law is doubtless in force with more or less strength wherever moisture falls and plants grow, but the class of trees that thrive here require a loose, sandy soil, and are often seen growing where there is no earth in sight at all clinging to the sides of the cliffs, so bare that the roots run along the surface entirely uncovered until they reach some crevice which they fill, and send tendrils down to draw sustenance from an unseen source. In such places the melting snow disappears quickly from the surface, and, except for their influence in keeping the soil light and porous so that the water can be absorbed readily instead of running off, it matters but little whether trees are there or not. No moisture remains upon the top of the ground long for shade to protect. It goes either into the air or else into the ground, and it is a well-known fact that a very large portion of water which finds its way down the steep sides of the Sierras disappears near its sources and is found again far below, either in springs, by means of artesian wells, or in the increased flow of the parent stream. Indeed, a number of very respectable rivers, not only in the mountains, but in some of the valleys, seem to owe their existence to such distant and hidden sources. If the trees have any direct power here it seems to be to draw from deep beneath the surface the moisture which has sunk into the earth and exhale gallons and gallons of it hourly. Any good-sized tree has been estimated to have a capacity of forty or fifty gallons every twenty-four hours, and a forest of such trees would effect very considerable results.

"I should like to offer the opinion of Captain J. B. Overton, of Virginia City, Nevada, just here. He has had control of the water supply of that city for many years, and also conducted large operations in the mountains in cutting timber, wood and lumber for the mines. His experience covers a quarter of a century and extends over several townships of land, from which his men cut the timber. He says:

"'My experience proves to me that the cutting of the timber makes no difference in the amount of snow that falls, but that it drifts more and for that reason lasts about as late in the summer as it would before the removal of the shade. I do not think the streams get low any sooner or afford any less water. I am of the opinion that the trees absorb from the soil quite as much water as would be

evaporated by the action of the sun in the absence of shade. I know two small springs that ran for the whole year for ten years after the land was cut over, but, that since the thrifty growth of young pines have reached a height of from 15 to 25 feet and shade the ground as well, if not better, than the large trees did, have dried up about the last of August for five years past, and I can see no cause for it except that the trees are using the water. The supply of water used by my company in its operations has not decreased with the disappearance of the timber, and I do not find that the freshets are any more frequent or more violent than before the trees were cut off. The trees are coming up in a second growth much more numerously than they were before, and after sixty or seventy years about nine-tenths of them will die off and decay, leaving the timber about as it was when we first came to this country; then I think my springs will flow again. My observation teaches me that the amount of rainfall is not affected by denuding the mountain-side, but that the surface of the ground will therefore be drier, but that streams and the springs will be more diminished by the water used by the trees than by evaporation in their absence.' Mr. Chittenden.

* * * * * * * * * *

"Trees tend to dissipate the snows in the Springtime also, by breaking up the steady cold winds that come down from the north at that season, almost invariably. When the current is permitted to flow on in uninterrupted sweep it retains the chill, but let it strike a forest and wind in and out among the trees for a mile or two and there will be a decided change in the temperature. It will be much better prepared to absorb moisture and also to melt the snow banks in its changed form as it pursues its southern journey.

"But the strongest force at work to save our rivers is the drifting winds which heap up the snow in great banks, and in this the trees are a constant obstacle. There will be miniature drifts, it is true, but nothing to what they are when there is no obstruction. Outside the timber belt, where there is nothing to catch the snow as it falls and nothing to break the force of the wind, one of the most powerful and active agents in preserving the water supply of the country comes into play. By forming solid bodies of snow, the most effective means of saving water for summer is reached. Across the bleak summits and down the vast canyons the wind has a well-nigh irresistible force, and it not only gathers up the snow after it has ceased to come down, but it usually keeps at work all the time it is falling and carries it in whirling clouds until it strikes a cliff or a canyon set at just the right angle and there it deposits the whole load. As long as there is any material left outside to work upon this is kept up, and there is no knowing how deep some of the big drifts get to be in the course of a long winter. As the days get warmer, the surface thaws a little and moistens the cake down a few inches, but the cold nights found all the year round at such altitudes soon transform it into ice, making a crust upon which the heat of the sun and the absorbing power of the air find it difficult to make any impression. On open ground the process is aided by the packing power of the wind, and it is not an unusual thing to see a man on horseback traveling comfortably across snow-

Mr. Chittenden.

banks high enough to hide both the horse and rider many times over if they should chance to break through. It is this which has changed the opinion of four settlers out of five along the eastern base of the Sierra Nevadas, where the timber has been cut for the Comstock mines. Over half a billion dollars in treasure have been taken from that one lode, and it is said that for every ton of ore taken out the equivalent of a cord of wood has gone either in the shape of timber or of fuel. The whole mountain side for a distance of thirty miles has been cut over, covering the heads of such streams as Hunter's Creek, Galena, White's Canyon, Thomas Creek, Steamboat, and other small rivers, which have furnished water for irrigation since 1860 to the owners of probably twenty thousand acres of land in the valleys below. The consensus of opinion among this class of citizens, intelligent American farmers all of them, is that there is virtually no diminution in the supply of water that reaches them from the hills. James Mayberry had charge of two men who cut over twelve thousand acres in the early '70s. He is of the opinion that Hunter's Creek, with which he is most familiar, has a more certain flow and somewhat more water than before. John Wright has lived thirty years on Steamboat Creek. It was dry in 1864, when the timber was standing, but never has been since, and has furnished water for a constantly increasing settlement. Robert Jones lives on low land, and says he has had more crops killed by flooding in the ten years after the timber was cut than in the ten years before it was touched. G. R. Holcomb says the supply is equally certain if not more so and attributes it entirely to the drifting of the snows. Several made answer that the water melted earlier and ran off sooner and said anyone would know that, but failed to convince even themselves that they were lower than in former years.

"Hon. Ross Lewers, of this country, read a paper before the American Horticultural Society a few years ago in which he said: 'There are certain peculiar conditions that prevail in Nevada that I think worthy of notice. One of them is, that wherever the forest timber has been cut off, a new growth has sprung up much thicker, and none of the young trees will start until the old ones are gone. Another is, that the water supply from the mountains is greater and more permanent now than it was before the timber was cut off. The reason for this is, that the wind has a more unimpeded course, and as all the snow storms come from nearly the same point in the south, the snow is blown over the ledges on the north sides of the ridges where it is piled deep in drifts, and not being exposed directly to the sun's rays it melts very slowly and thus affords a more permanent supply. Spring floods are less frequent and for the same reason. I do not pretend to decide how much, if any, the presence of the trees induces precipitation. They may moisten the air, but the humidity is all taken out of the ground by the roots, and I observe that the undergrowth and grass is more luxuriant since the timber was cut off.'

"As I have laid much stress upon this matter of evaporation, which some may think hardly applies to snow, I will say that a considerable body has been known to disappear from our streets without making a particle of mud, leaving the ground dusty, showing that none of it melted, but that it all went directly into the air. And this

Mr. Chittenden.

will occur any time when the thermometer does not go above thirty-two degrees within a short time after a storm. The importance of presenting as small a surface to the action of such an air as that is very apparent, and it is in storing up the snow in heaps and packing it away in deep pockets that the economy of nature is manifested. The center of the body will not melt at any time, and it requires a very warm day to get at the underside of the snowdrift. The grass will be growing all around it before the ground underneath it gets warmed up sufficiently to start a stream from it, but let a tree stick its head up through the crust and it [the snow] will go quickly. I have yet to see the first body of perpetual snow lying among the trees. It will hardly do to say that the timber lies below the line of perpetual snow, for there are many banks which only disappear entirely once in ten years or so (when there comes a long dry summer), which have trees growing higher up on the same mountain side.

"In any case, I do not wish to be understood as favoring the destruction of the forests of this or any other country. I never cut down a tree in my life and never saw one fall without feeling that I had lost a friend. Whatever is proven, there will always be abundant reasons for preserving extensive tracts of woodland everywhere that trees will grow, and it is time the matter became one of public concern."

IV.

The following extract is given on account of its historic interest, and because it presents in exaggerated form the quixotism of the Ohio River reservoir project which the writer has criticized in his paper. It is from a book written by Colonel Charles Ellet, Jr., entitled "The Mississippi and Ohio Rivers;" published in 1853, pages 303 to 305.

"Reservoirs may eventually be made of sufficient capacity to hold *all* the annual excess, and make the daily flow almost entirely uniform. The banks of the Ohio and Mississippi, now broken by the current and lined with fallen trees, ready to be swept by the next freshet into the channel, there to form dangerous snags, may yet, in the course of a very few years, be cultivated and adorned down to the water's edge. In the opinion of the writer, the grass will hereafter grow luxuriantly along the caving banks; all material fluctuations of the waters will be prevented, and the level of the river surface will become nearly stationary. Grounds, which are now frequently inundated and valueless, will be tilled and subdued; the sandbars will be permanently covered, and, under a uniform regimen of the stream, will probably cease to be produced. The channels will become stationary. The wharves will be built as the wharves on tide water, with little, if any, reference to the fluctuations of the surface. The lower streets of all the river towns, no longer exposed to inundations, will acquire new value. The turbid waters will be arrested in the upper pools, and the Ohio first, and ultimately the Missouri and Mississippi, will be made to flow forever with a constant, deep, limpid stream. The ice will be swept off as it forms, and neither cold nor drought will longer be suffered injuriously to affect the navigation. The ocean steamers will

Mr. Chittenden.

not then be confined to tide-waters, but will be able safely to ascend the living streams to seaports on their borders, and the extent of the inland navigation will be limited only by the limit to the water which is supplied by the atmosphere.

"All this may be accomplished on the Ohio *for about the cost of three or four ships of the line.* The great and only difficulty is, so far to overcome the cold incredulity of the public as to obtain from Congress a sufficient appropriation for the completion of the first two reservoirs. This once effected, and a single practical demonstration made, it will perhaps be as difficult to convince the future engineer that a thing so clear and palpable could ever have been doubted, as it at first was to remove the doubts."

ERRATUM.

On page 509, ninth line from the bottom, insert the word "million" after the word "thousand," so that the sentence will read "A little while ago the country was told that a thousand million tons of soil are yearly washing from our agricultural lands into the sea," etc.

MEMOIRS OF DECEASED MEMBERS

THOMAS FITCH ROWLAND, Hon. M. Am. Soc. C. E.*

DIED DECEMBER 13TH, 1907.

The name of Mr. Rowland will be, each year, recalled to the Society when the award of the Thomas Fitch Rowland Prize is announced at the Annual Meeting. The prize was originally instituted by the Society at the Annual Meeting of 1882, in recognition of the generous action of Mr. Rowland in connection with the fund created for assuring to the Society the permanent ownership of a building suitable for its needs and its growth. Mr. Rowland did not know that the institution of this prize was contemplated, and, when he was informed that it had been done, he insisted upon giving to the Society the amount, the annual interest of which now provides the prize. At the request of the Board of Direction, he suggested the conditions for the award, namely, that the paper for which the prize is given shall describe accomplished works of construction, state their cost, and especially note any errors, in either design or execution, which may have developed during construction. His long and varied experience in construction led to the desire that engineers connected with the progress of works should be encouraged to describe, not only the finished results, but also those changes and modifications which might occur during their progress, and from which he believed much useful knowledge would be given for guidance in other and future work.

Thomas Fitch Rowland was born in New Haven, Connecticut, on March 15th, 1831. He was the son of George Rowland and Ruth Caroline Attwater. He was a lineal descendant of the Honorable Thomas Fitch, the last colonial governor of Connecticut.

He was educated at the public schools of New Haven. At an early age he acted as miller's boy in his father's grist mill. This mill was demolished upon the construction of the New York, New Haven and Hartford Railroad, and he became the first apprentice in the machine shop of that road. While in that employ he was detailed for, and acted as, fireman of the locomotive on the third passenger train which ran from New Haven to New York.

In 1850 Mr. Rowland left the railroad and became Second Assistant Engineer of the *Connecticut*, a large side-wheel steamboat, carrying passengers and freight between Hartford and New York.

His next service was with the Allaire Works of New York, large builders of steam engines. While with them he designed the engines

* Memoir prepared by the following Committee: John Bogart, George S. Greene, Jr., Edward P. North, and Theodore Cooper, Members, Am. Soc. C. E.

of the U. S. revenue steamer, *Harriet Lane*. He then entered the Morgan Iron Works, owned and operated by George W. Quintard. He made the designs, specifications, and estimates of cost of the machinery for the U. S. gunboat, *Seminole*, and was put in charge of the construction of that machinery. He then took charge as Superintendent of Construction of an iron side-wheel steamboat which Mr. Quintard built at Greenpoint, Long Island, for use at New Orleans. Associated with him in that work was Mr. Samuel Sneden, a prominent builder of wooden vessels. He and Mr. Rowland then formed a partnership for building iron and wooden steamers, and general structural work. The first contract obtained by this firm was the construction, for the Croton Aqueduct Department of New York City, of a wrought-iron water pipe 7½ ft. in diameter, about ¼ mile in length, and located on the top of the High Bridge over the Harlem River. Another early contract was for an iron vessel designed by the late John Ericsson, Hon. M. Am. Soc. C. E. This firm also built the hulls for the steamboats, *Continental*, the *City of Boston*, and the *City of New York*. Mr. Sneden left the firm in 1860, and Mr. Rowland thereafter continued the enterprise under the name of The Continental Iron Works. Early in 1861 he built a number of naval gun carriages. He also built twenty revolving mortar-bed carriages for the Navy Department. These, with their mounted mortars, were installed on a number of vessels which, during the Civil War, were known as the Porter Mortar Fleet.

In 1861, for John Ericsson and associates, Mr. Rowland built the iron-clad, single-turret, floating battery, at first called Ericsson's battery, but directly designated the *Monitor*. This was the original *Monitor* which arrived in Hampton Roads during the night of the day on which the Confederate iron-clad, *Merrimac*, had sunk the U. S. frigate, *Cumberland*, had driven ashore the U. S. frigate, *Congress*, which was entirely burned, and which doubtless during the next day would have captured or destroyed the frigates, *Minnesota* and *Roanoke*, and other smaller vessels, and thus opened the way to Northern harbors. The struggle during the next day between the great iron-clad, *Merrimac*, and the comparatively diminutive *Monitor*, and the final victory of the *Monitor*, are notable events in naval history, which determined new departures in naval construction and armament. The speed as well as the thoroughness of construction of this original *Monitor* was notable, particularly as the vessel differed in nearly every feature from anything previously built.

Mr. Rowland immediately proceeded with the construction of the monitors, *Montauk*, *Kaatskill*, and *Passaic*, and the double-turreted monitor *Onondaga*. He also built the light-draft gunboats, *Cohoes* and *Muskoota*.

In 1870 he built the ferry-boats, *Fulton*, and *Farragut*, and after-

ward the *Atlantic,* and the *Brooklyn,* all for service between New York and Brooklyn.

For many years Mr. Rowland devoted great attention to the design of gas-manufacturing installations, and he built a large number of these in various parts of the United States. Among the very large ones are those of the Commercial Point Station of the Boston Gas Company, and the Twenty-first Street, the Forty-fourth Street and the Ninety-ninth Street Stations of the Consolidated Gas Company of New York. The Fourteenth Street gas-holder and steel tank for the same Company, also designed and built by him, was, at the time of its construction, the largest of its kind in the United States and a notable achievement in gas engineering.

In 1887, his business was incorporated as The Continental Iron Works, Mr. Rowland being its President up to the time of his death.

For many years Mr. Rowland had devoted much study to the perfection of the art of welding iron and steel plates in various forms and shapes, and, about 1887, he designed the process and the requisite machinery for the manufacture of the Fox corrugated and the Morison suspension furnaces now used in the well-known internal type of boiler.

In 1855 Mr. Rowland married Mary Elizabeth Bradley, of New Haven, who died in March, 1902. He is survived by two sons, Thomas F. and Charles B. They have been associated with him in The Continental Iron Works, and both of them are Members of the Society.

Mr. Rowland continued in active touch with his works until within a few months of his death, although he had been in failing health for several years. He was a devoted member of the Episcopal church, having joined it in early life. He had many charitable, philanthropic, and historical interests. Although he had to do with such important works, during a long and remarkably active life, he was always of a modest character and retiring disposition.

He took the greatest interest in the welfare and progress of the American Society of Civil Engineers. During the periods of its growth, when many perplexing problems were encountered by its officers, they could, and always did, receive from him substantial aid and well-considered and judicious advice. Recently, in 1905, when in connection with the enlargement of the Society building, a temporary loan was suggested from several members, Mr. Rowland replied that he did not care to loan the Society any money, but sent to the Secretary $5 000 as a donation.

Mr. Rowland was elected a Member of the American Society of Civil Engineers on December 4th, 1867, and was made an Honorary Member on December 20th, 1899. He served as a Director in 1871, 1872, and 1873, and as Vice-President in 1886 and 1887.

RICHARD MILFORD BERRIAN, M. Am. Soc. C. E.*

DIED DECEMBER 23D, 1907.

Richard Milford Berrian was born in New York City on May 17th, 1850, of old Colonial stock, his father, S. M. Berrian, being of the Fordham Huguenot family of that name, while his mother, a Grover, of Bethel, Maine, was a lineal descendant of the Puritan Masons. The boy was educated in the public and private schools of New York City, his attention being given principally to such studies as would fit him for engineering work. In 1869, at the age of nineteen, he entered the employ of the New York and Harlem Railroad Company as draftsman, in the Engineering Department, under the late Isaac Craig Buckhout, M. Am. Soc. C. E., who was at that time Superintendent and Chief Engineer. Mr. Berrian early showed the energy, ability, and accuracy that characterized all his work, and in 1871 he was promoted to the position of Assistant Engineer in charge of the construction of terminals at the Grand Central Station. In the following year, he was made Division Engineer in charge of a portion of the improvement of the Harlem Line on Fourth Avenue between Forty-second Street and the Harlem River, in New York City, for the elimination of grade crossings and the construction of four tracks.

This position Mr. Berrian held until the completion of the work in 1876, from which time until 1890 he had supervision of several important works, notably the survey and construction of the Manhattan Beach Railroad, as Assistant Engineer; the Boston, Hoosac Tunnel, and Western Railway, as Assistant and Chief Engineer, and as Division Engineer for the location and construction of the Buffalo Division of the New York, Lackawanna, and Western Railroad.

From 1890 to 1907 he was continuously in the employ of the New York, New Haven, and Hartford Railroad Company in charge of numerous large and expensive works, among which are the improvements through South Norwalk and Bridgeport, the construction of four-track draw-bridges across the Connecticut River, Pequonnock River, and Norwalk River, the six-track lift bridge across the Fort Point Channel at the South Terminal, Boston, Massachusetts, and at the time of his death he was in charge, as Chief Engineer, of the construction of the bridge over the Taunton Great River at Fall River, under the direction of a joint committee composed of the Railroad Commissioners, the Harbor and Land Commissioners of Massachusetts, and the County Commissioners of Bristol County.

Mr. Berrian was one of the ablest engineers of his day. An expert draftsman, his designs were definite, accurate and easily understood.

* Memoir prepared by S. L. F. Deyo and F. S. Curtis, Members, Am. Soc. C. E.

His modesty in all professional matters was such that his ability was only known to those with whom he came in personal contact.

He was successful in all his undertakings, putting his whole strength and time into the work that he had in hand, and, although he was very exacting in requiring his plans and orders to be carried out promptly and accurately, he was quick to recognize merit and to give full credit to all his employees for their work, commanding their respect and that of his employers.

On September 24th, 1879, Mr. Berrian was married to Miss Belle M. Macduff, of New York City, who survives him.

Mr. Berrian was elected a Member of the American Society of Civil Engineers on May 4th, 1887.

STEPHEN ARNOLD MITCHELL, M. Am. Soc. C. E.*

DIED MAY 21ST, 1908.

Stephen Arnold Mitchell was born at Point Pleasant, Ohio, in 1863. He was of Scotch-Irish parentage, his ancestors being among the early settlers of the State of Maryland. In 1868 he came to Kansas City, Missouri, where he received his early education, being graduated at the age of sixteen from the Central High School. In 1883, he was graduated from the Missouri State University, receiving the degrees of B. S. and C. E.

Immediately after graduation Mr. Mitchell commenced the practice of his profession under Messrs. Knight and Bontecou, Civil Engineers, in the location and construction of the Kansas City Belt Railroad. After the completion of this work he spent one year in the Engineering Department of Kansas City, confining his attention chiefly to the construction of sewers and paving. For about six years, from 1886 to 1892, he devoted himself to the general practice of his profession, making surveys and soundings to guide in the location of the Chicago, Milwaukee and St. Paul Railroad Bridge across the Missouri River at Randolph, Missouri, and assisting in the construction of a line of railroad connecting that bridge with the Kansas City Belt Line Railroad. Later, he associated himself with Mr. John W. Neir and an older brother, under the firm name of Mitchell and Neir, and for several years was very active in the design and construction of waterworks in many towns of the rapidly developing State of Kansas, in Fort Payne, Alabama, and in Elwood, Indiana.

From 1892 to 1901 Mr. Mitchell was Assistant City Engineer of Kansas City, Missouri, serving the city with a degree of fidelity and self-sacrifice that won for him numerous friends and many staunch supporters regardless of political affiliations. He left the service of the city from choice, well equipped by experience to assume weightier and more independent responsibilities. So great was the confidence he had inspired by his faithful service to Kansas City that his advice was frequently sought in all matters pertaining to municipal engineering. He assisted in placing a value upon the water-works property which Kansas City purchased from the National Water Company, and later became one of the members of a commission to devise extensive and comprehensive improvements in this system, acting for several years as Chief Engineer of Construction in carrying out the plans of the Commission.

In 1906, Mr. Mitchell planned more than 50 miles of sewers and a complete system of street improvements for Fort Smith, Arkansas, a

* Memoir prepared by Wynkoop Kiersted and Alexander Maitland, Jr., Members, Am. Soc. C. E.

city in which he had filled the important position of Consulting Engineer to the Board of Improvements for some time. He died on May 21st, 1908, at the age of forty-five. At the time of his death he was in personal charge of the construction of the public works he had designed for Fort Smith, and accordingly had taken up his residence in that city. He is survived by his wife.

Mr. Mitchell's devotion to his professional work, his uniformly genial disposition, and his profound integrity, won for him many life-long friends who mourn his death and feel keenly the loss of his good fellowship.

Mr. Mitchell was elected a Member of the American Society of Civil Engineers on October 2d, 1907.

GEORGE W. RAFTER, M. Am. Soc. C. E.*

DIED DECEMBER 29TH, 1907.

George W. Rafter was born in Orleans, Ontario County, New York, on December 9th, 1851, being the youngest of five children. His mother was Eleanor Willson, whose grandfather, James Willson, was identified with the Revolutionary history of Cherry Valley, New York. In 1739 he assisted in making the first survey of the region around Cherry Valley, for which he was given a tract of land on which his descendants still live. On his father's side, Mr. Rafter was of Scotch-Irish extraction, his great-great-grandfather Rafter having emigrated from the north of Ireland to Northumberland County, Pennsylvania, about 1750.

Mr. Rafter's father owned a developed water-power at Orleans, which operated a flouring mill and other manufacturing establishments, from which he made a comfortable living for the family and accumulated some property. Possibly the experience with that water-power in his boyhood was the influence which inclined Mr. Rafter toward the improving of water-powers in general by water storage, in later years (because, after his father's death, which occurred when Mr. Rafter was seven years old, this water-power was sold several times, but reverted back to his mother because of the inability of the purchasers to use it efficiently on account of the variation in the flow caused by the removal of forests, etc.).

That Mr. Rafter had an inherited taste for his chosen profession is indicated by the fact that he had, in his library, a book on mathematics printed in London in 1704, which his ancestor, James Willson, had brought with him when he came to America. An interesting incident in connection with this book is the fact that when James Willson was moving his family from Albany to Cherry Valley, by flatboat up the Mohawk, the chest in which it was contained slipped off into the river. The spot was marked, and the following spring the chest was recovered, but the book shows very plainly that it has been water-soaked.

Mr. Rafter was a prominent representative of the sturdy class of civil engineers who have had a controlling influence in shaping the development of this wonderful country on a scale of such magnitude as to be beyond the dream of our ancestors. He assisted materially in advancing the application of engineering in many directions. As a boy he attended the public schools, and later spent three years at the old Canandaigua Academy where his roommate and chum was Lyman E. Cooley, M. Am. Soc. C. E., and where his associates included many other men prominent in after-life. On leaving the Academy, he went to Cornell University.

* Memoir prepared by J. Y. McClintock, M. Am. Soc. C. E.

In 1872, Mr. Rafter married Miss Alyda Kirk, and they were a mutual help and comfort to each other for thirty-five years, bringing up to maturity two daughters, Ethel, now the wife of Dr. John R. Williams, of Rochester, New York, and Myra Willson, who, for several years past, has been an efficient aid to her father, assisting him as stenographer and computer in the preparation of his important reports. Mrs. Rafter died in May, 1907, and, after her death, Mr. Rafter was oppressed with lonesomeness, and, to a large extent, lost interest in his profession, so that, to those who knew him intimately, it seemed not unfitting that he should follow her so closely.

Beginning his engineering work in 1873, Mr. Rafter took a position in the City Surveyor's office at Rochester, where part of his time was occupied. At the same time he studied architecture in the office of A. J. Warner, with Ex-Mayor James G. Cutler as a fellow student. At this period he also found time to teach mathematics in a private school conducted by Professor Reed, where he made lasting friendships with boys who have since developed into the leading men of the community, such as the Honorable James Breck Perkins, Wheelock Rider, M. D., and others.

In 1876, he was Assistant Engineer on the Rochester Water-Works, while in 1877-78 he was in private practice as a civil engineer, filling, among other engagements, that of Engineer to the Rochester and Lake Ontario Railway Company. In 1880-82 he was Engineer on the construction of the Texas Pacific and Missouri Pacific Railways, having charge, in 1881, of the water supply of the Texas Pacific Railway across the "Staked Plains." In 1882-83 he was in charge of the construction of water-works at Fort Worth, Texas.

Mr. Rafter was Assistant Engineer of the Rochester Water-Works in 1883-87, and also Engineer of the water-works at Fredonia, New York. In 1883 he made a survey of Honeoye Lake with reference to converting it into a storage reservoir for the benefit of the Rochester mills. This was the beginning of the great work done by Mr. Rafter, in the study of the possibilities of regulating the Genesee River, which afterward occupied so much of his attention.

From June, 1888, to October, 1890, he was in charge of the additional water supply for the City of Rochester, and was Acting Chief Engineer of the Rochester Water-Works in 1890. During these years he showed how he had developed into a strong man. The city approached the limit of the capacity of the water-works, and the then Chief Engineer had advanced a project with unusual features, causing the business men of Rochester to doubt the soundness of his judgment, so that they even questioned the necessity of an additional supply, on the ground that the consumption per capita was beyond reason if the existing conduit was delivering the quantity of water for which it was designed. They insisted that, as a preliminary, means should be taken

to gauge the quantity of water delivered to the city, and that, with proper care, shortage of water might be prevented. The Chief Engineer asserted that it would be impossible to measure the water without causing a water famine, and that, under the conditions, it would be impossible to prevent a shortage of water to the citizens. A committee of the Chamber of Commerce induced Mr. Rafter to say that, if he had the responsibility, the water could be measured and a water famine avoided. The Committee took him at his word, and, upon its insistence, he was made Acting Chief Engineer. While occupying this position, he laid the City of Rochester under lasting obligation by introducing and operating an ingenious and unique scheme of throttling down certain districts, so that the insufficient supply was distributed in such a way as to preserve the public health and reduce discomfort to the lowest possible degree.

The following years were occupied with varied work, including sewage disposal at Albion and Holley, New York, and the West Virginia State Hospital for the Insane; water-works at Berwick and Nescopeck, Pennsylvania; sewage disposal works at Lawrenceville, and Geneva, New York; and Consulting Engineer to the Warsaw, New York, Water Company. In conjunction with Mr. M. N. Baker, Mr. Rafter prepared the exhaustive and comprehensive work, "Sewage Disposal in the United States," which has since been a standard textbook, and of great importance, because it was the first complete exposition, in the United States, of a subject then becoming of such vital importance and interest. It was dedicated by the authors "To the Health and Prosperity of American Cities and Towns," and there is no doubt that many such cities are under obligation to Messrs. Rafter and Baker for the information contained in this manual.

For some time Mr. Rafter had been preparing himself by studies with the microscope, and, while acting as Sanitary Expert to the Boston Water-Works, he, with Professor W. T. Sedgwick, devised the Sedgwick-Rafter method of water analysis, well known to biologists. Mr. Rafter was one of the pioneers in making practical use of the application of biology to city water supplies. He prepared several papers on this subject, including: "On the Fresh Water Algæ and their Relation to the Purity of Public Water Supplies";* "How to Study the Biology of a Water Supply"; "On Some Recent Advances in Water Analysis, and the Use of the Microscope for the Detection of Sewage Contamination"; "On the Micro-Organisms in Hemlock Water"; "Microscopical Examination of Potable Water"; and, together with Doctors Mallory and Line, a pamphlet entitled "On *Volvox Globator* as the Cause of the Fishy Taste and Odor of the Hemlock Lake Water in 1888."

In 1893 Mr. Rafter began work for the State of New York on the subject of controlling the flow of rivers and the construction of storage

* *Transactions*, Am. Soc. C. E., Vol. XXI, p. 483.

reservoirs, and, in connection with it, a comprehensive study of the hydrology of the State. His first work in this line was on the Genesee River, and consisted in making exhaustive surveys and borings, and designs for a great dam just above Mount Morris, at a site previously established by the State Engineer. In connection with this work, elaborate tests were made of the strength of concrete. In this study, he arrived at the conclusion that it would be more advantageous to locate the dam above the High Falls at Portage instead of at Mount Morris. A further appropriation having been made by the State, he was able, in the following years, to verify his conclusions by careful surveys, and to determine that, for a less expenditure, a reservoir of double the capacity could be created which, on account of the additional fall of 500 ft. available, would double the horse-power. Thus he fixed the plan of regulating the river which will be ultimately carried out.

During these years of work on the Genesee, with the aid of the Rochester Chamber of Commerce, many plans for carrying out the project were tried and many schemes were presented to the Legislature. Finally, at the suggestion of the Governor, who had vetoed a bill which provided for the work being commenced by the State, the Genesee River Company was organized, and legislative authority was secured for it to build the works. Mr. Rafter, more than any one else, worked out the details of these various campaigns and enlisted the capital necessary for such a company to begin operations. It was one of his disappointments that, because of the impossibility of securing the consent of the larger owners of water-power in Rochester, the company was unable to carry out the work begun by it.

He also made surveys for the regulation of the flow of the Hudson River by the establishment of reservoirs on its head-waters, and designed and superintended the construction of a great dam on Indian River, a branch of the Upper Hudson. He likewise planned several additional reservoirs, including the great one at Schroon Lake.

One result of these reports on the various rivers was the formation, in 1902, of the New York State Water Storage Commission, of which Mr. Rafter was a member. This Commission made a very valuable report, and recommended a law establishing a River Improvement Commission, to which power should be given for regulating any river in the State. This was adopted by the Legislature, in a modified form, and under it work was begun on several streams. Later, the River Improvement Commission was combined with the Water Supply Commission, which is now proceeding in a comprehensive manner to develop the natural resources of New York State.

In 1894, Mr. Rafter was sent abroad by the State Engineer of New York to study movable bridges in Europe, and at that time he spent several months in England, Holland, Germany, Italy, and France, on work relating to this subject. He also investigated several high

masonry dams, and, upon his return, made reports to the State Engineer on each of these subjects.

In 1898-99, Mr. Rafter had charge of the water-supply investigation for the United States Board of Engineers on Deep Waterways. Elaborate surveys and estimates were made for a ship canal at Oswego, from Lake Ontario through Oneida Lake and down the Mohawk River to the Hudson. This work was, perhaps, the most important of his undertakings, because it included a plan for the establishment of great reservoirs on the Black and Salmon Rivers, a water-supply canal of more than 90 miles in length, or an alternate tunnel some 28 miles in length, and also a thorough examination of the applicability of hydraulic formulas to heavy flows over weirs, and a set of experiments on a large scale far beyond anything in that line available at that time.

Since 1900 Mr. Rafter had been in private practice as a Consulting Engineer, during which time he made valuable reports on a variety of projects. In 1904, he prepared, for the State Geologist of New York, a report on the hydrology of the State, which is a recognized authority on matters relating to stream flow.

Mr. Rafter was largely instrumental in inducing the beginning of a systematic observation and record of stream flow, both by the State of New York and the United States Government, and his work on "The Hydrology of the State of New York" will be ever recognized as an important foundation for the great studies which have been begun looking toward the development of the immense national wealth to be continuously created by the streams of New York. He wrote five papers, published in the Water Supply and Irrigation Series issued by the United States Geological Survey, and, in the very complete engineering library which he had collected, were included fully 175 books and papers of which he was the sole or joint author. He was a very prolific writer, and, in addition to the books and papers which have been published, he had written innumerable professional reports.

Mr. Rafter was a good citizen, in the best sense of the word—he gave of his knowledge and experience freely for the benefit of Rochester, where he had raised the family he loved. As a member of the Chamber of Commerce, from its organization, he was ever ready and active in working for the best interests of the community. The writer knew him personally for twenty-five years, and saw a great deal of him, having worked with him on many occasions.

Mr. Rafter was an indefatigable worker, and, on any subject which interested him, he would strive to know it to its farthest detail. His brain was big, and contained a vast store of useful and entertaining information. Sometimes he was gruff, but his heart was warm, and he had a comprehensive regard for others, perhaps more especially for young engineers. He had a horror of their becoming what he termed "lackadaisical," and sometimes his advice to them was strongly worded,

but he was always anxious to explain and demonstrate when they were receptive. For several months, during the work on the Deep Waterways surveys, the writer was closely associated with Mr. Rafter, and enjoyed discussing with him all kinds of professional, religious, and other questions, and, for hours, he would recite from the most beautiful masterpieces in literature. He was a rather large man, physically, and the writer sometimes likened him to Samuel Johnson, whom he certainly compared with in capacity of brain. His voice was deep and musical, and sometimes his feelings were touched so that his recitations were most eloquent.

Mr. Rafter left his home in Rochester, New York, on December 1st, 1907, expecting to spend the winter in Europe looking up matters in which he was interested. While in Karlsbad, he contracted pleurisy, and died in two days.

Mr. Rafter was elected a Member of the American Society of Civil Engineers on April 2d, 1884. He was also a life member of Yonnondio Masonic Lodge, of Rochester, and belonged, as well, to the Rochester Engineering Society, Historical Society, Chamber of Commerce, Oak Hill Country Club, Masonic Club, Cornell Club of Rochester, American Forestry Association, American Geographic Society, Society for the Protection of the Adirondacks, Society of the Genesee, and American Water Works Association.

CHARLES HAROLD TUTTON, M. Am. Soc. C. E.*

DIED JUNE 19TH, 1908.

Charles Harold Tutton, the eldest son of George and Sarah Henry Tutton, was born in Tunkhannock, Pennsylvania, on May 10th, 1851. When eleven years of age, he entered a country printing-office, where he remained until he was fifteen. In March, 1867, Mr. Tutton entered the service of the Lehigh Valley Railroad as an engineer, and from 1869 to 1872 attended the Rensselaer Polytechnic Institute at Troy, New York.

Between 1871 and 1873, he located and built the Montrose Railway, in Pennsylvania, and also worked on railroads in New Jersey. From 1874 to 1877, he was engaged in mining and general engineering with I. A. Sterns at Wilkes-Barre, Pennsylvania. In 1878 he was employed in bridge engineering at South Bend, Indiana, but, in 1879, he returned to Wilkes-Barre, and was engaged in bridge engineering and mining until 1882. At that time he moved to Buffalo, where he resided until his death.

Mr. Tutton was connected with the Lehigh Valley Railroad from 1882 to 1888. He designed and built all the Tifft farm improvements, canals, coal trestles, and the shore protection along Lake Erie on the Hamburg Turnpike. He also built that company's coal trestles in Chicago.

From 1889 to 1892, Mr. Tutton was engaged on general work for contractors, and, during this time, built a number of trestles on the Adirondack and St. Lawrence Railroad, the Lehigh Valley coal trestle at Cheektowaga (the largest in the world), the new Buffalo city reservoir, etc.

Since 1893 Mr. Tutton had been connected with the Bureau of Engineering (Department of Public Works), of Buffalo, New York, and had charge of the erection of the steel liberty pole on the Terrace, city dredging operations, Buffalo river improvements, designing and constructing the sewer system of South Buffalo, and constructing the bridge over Cazenovia Creek, city survey, plans for the proposed new water-works, etc. In 1889 he was a candidate for City Engineer, but was defeated.

In December, 1882, Mr. Tutton married Fannie C. Draper at Tamaqua, Pennsylvania, who, with three daughters and one son, survives him.

Mr. Tutton was an able and successful engineer, and was known throughout the country as a genius in mathematics. He contributed

*Memoir prepared by the Secretary from information furnished by Mr. Tutton's family.

many articles and papers to engineering magazines, among them, "Flow of Water Through Pipes" in 1896. His personal mathematical manuscripts are marvels to all who knew him.

Mr. Tutton was elected a Member of the American Society of Civil Engineers on October 2d, 1901. He was also a Member of the Western Society of Engineers since 1877; of the Engineers' Society of Western New York from its inception; and of the American Association for the Advancement of Science.

CLARENCE GEORGE VAUGHN, M. Am. Soc. C. E.*

DIED AUGUST 4TH, 1908.

Clarence George Vaughn was born in Geauga County, Ohio, on September 25th, 1853. He was the son of G. W. Vaughn, M. Am. Soc. C. E.

At the age of eighteen years, Mr. Vaughn was employed in the Engineer Corps of the Kansas Central Railroad in the humble position of Axeman, but was rapidly promoted to Rodman, Levelman, and Instrumentman. Subsequently, he accepted the position of Assistant Engineer of the Kansas City, Wyandotte and Northwestern Railroad at Independence, Missouri, and, later, was employed by the Denver and Rio Grande Railroad as Assistant to the Division Engineer on the Leadville and Wheeler Branch. He was transferred to Poncha Springs, on the line from Salida to Gunnison, as Division Engineer, in 1880, and resigned shortly afterward to enter the service of the Mexican Central Railroad in the City of Mexico. From 1882 to 1885 he did miscellaneous work in Kansas City and vicinity.

From 1885 to 1889, Mr. Vaughn was in the employ of the Chicago, Milwaukee and St. Paul Railway, as Assistant Engineer, doing special work both in the office and in the field. His health began to fail at this time, and, for some months, he was incapacitated for work. He finally recovered and, in 1890, entered the service of the New Orleans and North Western Railroad as Assistant Chief Engineer. He became Chief Engineer in 1893, which position he held until 1904, meantime also undertaking, in 1901, the position of Chief Engineer of the Eldorado and Bastrop Railroad.

In 1905, Mr. Vaughn did business as Consulting Engineer at Natchez, Mississippi, but evidently could not resist the fascination of railroad engineering, for in December, 1905, he took charge of the construction of the Southern Pacific Railroad Company's line from Lafayette to Port Allen, Louisiana, as Construction Engineer, in which position he served until August, 1907, when he went to his Natchez home in an unsuccessful attempt to recover his health. He gradually grew weaker and, after suffering for a year, entered into rest on August 4th, 1908.

The greater part of the last eighteen years of Mr. Vaughn's life had been spent in the swamps of Louisiana and Arkansas, which no doubt contributed to his ill-health and tended to shorten his useful life.

Mr. Vaughn was an accomplished engineer, and was a gentleman of the highest possible type, a veritable Chevalier de Bayard, "without

* Memoir prepared by J. F. Coleman, M. Am. Soc. C. E.

fear and without reproach." His disposition was modest and retiring, and his thoughtfulness of the comfort and feelings of those about him was ever a source of wonder and pleasure to them. It is not fulsome praise to say that it was a genuine privilege to have known him, and that no man could know him well without being a better man for it.

He is survived by his father, G. W. Vaughn, M. Am. Soc. C. E., by a son who is practicing medicine in Kansas, and by his widow who resides in Natchez, Mississippi, whose grief is shared by hosts of friends, for truly "none knew him but to love him."

Mr. Vaughn was elected a Member of the American Society of Civil Engineers on November 7th, 1906.

JAMES ISAAC HAYCROFT, Assoc. M. Am. Soc. C. E.*

DIED APRIL 11TH, 1908.

James Isaac Haycroft was born in Cork, Ireland, on May 25th, 1853. In 1869 he commenced the study of engineering at Queen's College, Cork. After a distinguished career as a student, he obtained the degree of Bachelor in Engineering in 1872; and, in 1882, the degree of Master of Engineering was conferred upon him.

On the completion of his academic training, Mr. Haycroft entered the office of B. B. Stoney, M. Inst. C. E., of Dublin, Ireland, under whom he had unusual opportunities for acquiring experience in the design and construction of harbour and dock works in connection with the Port of Dublin; he afterward occupied positions as Assistant to the County Surveyor at Antrim and at Clonmel, and was Local Surveyor at Carrick-on-Suir. For some time Mr. Haycroft was associated with the firm of Messrs. Wells, Owen and Elwes, Civil Engineers, of London. In 1886, he left England for Australia. He spent about a year in Sydney, qualifying as a licensed Surveyor of Crown Lands and Real Property, and, in 1887, he obtained the two certificates.

For about eleven years Mr. Haycroft occupied the position of Borough Engineer of Woollahra, Sydney, and, at the same time, he carried on the practice of a Consulting Engineer. He resigned the position of Borough Engineer to accept one as Engineer in the Tramway Construction Branch of the Public Works Department, and remained in that Department until within a few days of his death.

Mr. Haycroft was a Member of the Institution of Civil Engineers of Ireland, an Associate Member of the Canadian Society of Civil Engineers, and a Member of the Society of Municipal and County Engineers, England. He was also a Member of the Royal Society of New South Wales and of several local societies, to which he contributed papers on technical and professional subjects, including bridge construction, roads, drainage, etc.

Mr. Haycroft had a wide range of scientific and technical knowledge, was a close reader, and was devoted to his profession. His death came as a great surprise and grief to his numerous friends. He married Julie S. A. Bowen, of Nottingham, England, who survives him.

Mr. Haycroft was elected an Associate Member of the American Society of Civil Engineers on January 3d, 1894.

* Memoir prepared by Professor W. H. Warren, University of Sydney, Sydney, Australia.

TRANSACTIONS

OF THE

American Society of Civil Engineers

INDEX

VOLUME LXII

MARCH, 1909

SUBJECT INDEX, PAGE 566
AUTHOR INDEX, PAGE 569

Titles of papers are in quotation marks when given with the author's name.

VOLUME LXII

SUBJECT INDEX

BRIDGES.

"The Sinking of the Piers for the Grand Trunk Pacific Bridge at Fort William, Ontario, Canada." H. L. Wiley. (With Discussion.) 113.

CAISSONS.

"The Sinking of the Piers for the Grand Trunk Pacific Bridge at Fort William, Ontario, Canada." H. L. Wiley. (With Discussion.) 113.

COFFER DAMS.

"The Sinking of the Piers for the Grand Trunk Pacific Bridge at Fort William, Ontario, Canada." H. L. Wiley. (With Discussion.) 113.

COMMERCE.

"Notes upon Docks and Harbors." Luther Wagoner. (With Discussion.) 135.

CRANES.

Use of — on docks. 144.

DOCKS.

"Notes upon — and Harbors." Luther Wagoner. 135. Discussion: W. B. Ruggles, E. P. Goodrich, Howard J. Cole, and Rudolph Hering, 149.

ELECTRIC POWER.

"The Hydro-Electric Development and Transmission Lines of the Canadian Niagara Power Company." A. H. Van Cleve. 199. Discussion: John C. Parker, and William J. Boucher, 238.

ELECTRIC RAILWAYS.

"Catenary Trolley Construction." Oliver S. Lyford, Jr. 157. Discussion: Joseph Mayer, Charles Rufus Harte, W. K. Archbold, Theodore Varney, George N, Cole, W. S. Murray, and R. D. Coombs, 175.

FORESTS.

"— and Reservoirs in Their Relation to Stream Flow, with Particular Reference to Navigable Rivers." H. M. Chittenden. (With Discussion.) 245.

FOUNDATIONS.

"The Sinking of the Piers for the Grand Trunk Pacific Bridge at Fort William, Ontario, Canada." H. L. Wiley. 113. Discussion: C. R. Fickes, George B. Francis and Robert A. Marshall, and F. W. Skinner, 120.

HARBORS.

"Notes upon Docks and —." Luther Wagoner. (With Discussion.) 135.

IRRIGATION.

"Irrigation." An Informal Discussion. George G. Anderson, F. H. Newell, J. P. A. Maignen, A. L. Fellows, W. W. Follett, Gardner S. Williams, F. C. Finkle, Thomas H. Means, G. N. Houston, Richard R. Lyman, and Arthur P. Davis, 1.

MEMOIRS OF DECEASED MEMBERS.

Berrian, Richard Milford. 550.
Haycroft, James Isaac. 564.
Mitchell, Stephen Arnold. 552.
Rafter, George W. 554.
Rowland, Thomas Fitch. 547.
Tutton, Charles Harold. 560.
Vaughn, Clarence George. 560.

PILES.

"Notes upon Docks and Harbors." Luther Wagoner. (With Discussion.) 135.
Steel sheet-piling. 129

POWER PLANTS.

"The Hydro-Electric Development and Transmission Lines of the Canadian Niagara Power Company." A. H. Van Cleve. (With Discussion.) 199.

POWER TRANSMISSION.

"The Hydro-Electric Development and Transmission Lines of the Canadian Niagara Power Company." A. H. Van Cleve. (With Discussion.) 199.

RAINFALL.

"Forests and Reservoirs in Their Relation to Stream Flow, with Particular Reference to Navigable Rivers." H. M. Chittenden. (With Discussion.) 245.

RESERVOIRS.

"Forests and — in Their Relation to Stream Flow, with Particular Reference to Navigable Rivers." H. M. Chittenden. (With Discussion.) 245.

RIVERS.

"Forests and Reservoirs in Their Relation to Stream Flow, with Particular Reference to Navigable —." H. M. Chittenden. 245. Discussion: F. Collingwood, Thomas P. Roberts, Stephen Child, L. J. Le Conte, F. B. Maltby, J. Francis Le Baron, Edward P. North, A. Miller Todd, William W. Harts, George Otis Smith, George F. Swain, W. H. Leffingwell and A. M. Strong, Bailey Willis, M. O. Leighton, W. D. Pickett, Robert E. McMath, H. F. Labelle, Emil Kuichling, Robert Fletcher, J. P. Snow, Clarence T. Johnston, and Gifford Pinchot. 319.

RUN-OFF.

"Forests and Reservoirs in Their Relation to Stream Flow, with Particular Reference to Navigable Rivers." H. M. Chittenden. (With Discussion.) 245.

SNOW.

"Forests and Reservoirs in Their Relation to Stream Flow, with Particular Reference to Navigable Rivers." H. M. Chittenden. (With Discussion.) 245.

STREAM FLOW.

See **WATER, FLOW OF, IN OPEN CHANNELS.**

TURBINES.

See **WATER WHEELS.**

WATER, FLOW OF, IN OPEN CHANNELS.

"Forests and Reservoirs in Their Relation to Stream Flow, with Particular Reference to Navigable Rivers." H. M. Chittenden. (With Discussion.) 245.

WATER, FLOW OF, IN PIPES.

"Curve Resistance in Water Pipes." Ernest W. Schoder. 67. Discussion: George Jacob Davis, Jr., 97.

WATER POWER.

"The Hydro-Electric Development and Transmission Lines of the Canadian Niagara Power Company." A. H. Van Cleve. (With Discussion.) 199.

WATER WHEELS.

"The Hydro-Electric Development and Transmission Lines of the Canadian Niagara Power Company." A. H. Van Cleve. (With Discussion.) 199.

AUTHOR INDEX

ANDERSON, GEORGE G.
Irrigation. 1, 53.

ARCHBOLD, W. K.
Catenary trolley construction, 185.

BERRIAN, RICHARD MILFORD.
Memoir of. 550.

BOUCHER, WILLIAM J.
Canadian Niagara power plant. 241.

CHILD, STEPHEN.
Forests, reservoirs, and stream flow. 328.

CHITTENDEN, H. M.
"Forests and Reservoirs in Their Relation to Stream Flow, with Particular Reference to Navigable Rivers." 245.

COLE, GEORGE N.
Catenary trolley construction. 190.

COLE, HOWARD J.
Docks and harbors. 153.

COLLINGWOOD, F.
Forests, reservoirs, and stream flow. 319.

COOMBS, R. D.
Catenary trolley construction. 194.

DAVIS, ARTHUR P.
Irrigation. 52.

DAVIS, GEORGE JACOB, Jr.
Curve resistance in water pipes. 97.

FELLOWS, A. L.
Irrigation. 19.

FICKES, C. R.
Sinking bridge piers. 120.

FINKLE, F. C.
Irrigation. 37.

FLETCHER, ROBERT.
Forests, reservoirs, and stream flow. 447.

FOLLETT, W. W.
Irrigation. 22.

FRANCIS, GEORGE B.
Sinking bridge piers. 123.

GOODRICH, E. P.
Docks and harbors. 152.

HARTE, CHARLES RUFUS.
Catenary trolley construction. 180.

HARTS, WILLIAM W.
Forests, reservoirs, and stream flow. 347.

HAYCROFT, JAMES ISAAC.
Memoir of. 564.

HERING, RUDOLPH.
Docks and harbors. 155.

HOUSTON, G. N.
Irrigation. 45.

JOHNSTON, CLARENCE T.
Forests, reservoirs, and stream flow. 454.

KUICHLING, EMIL.
Forests, reservoirs, and stream flow. 445.

LABELLE, H. F.
Forests, reservoirs, and stream flow. 437.

LE BARON, J. FRANCIS.
Forests, reservoirs, and stream flow. 333.

LE CONTE, L. J.
Forests, reservoirs, and stream flow. 329.

LEFFINGWELL, W. H.
Forests, reservoirs, and stream flow. 377.

LEIGHTON, M. O.
Forests, reservoirs, and stream flow. 394.

LYFORD, OLIVER S., Jr.
"Catenary Trolley Construction." 157.

LYMAN, RICHARD R.
Irrigation. 46.

McMATH, ROBERT E.
Forests, reservoirs, and stream flow. 430.

MAIGNEN, J. P. A.
Irrigation. 15.

MALTBY, F. B.
Forests, reservoirs, and stream flow. 332.

MARSHALL, ROBERT A.
Sinking bridge piers. 123.

MAYER, JOSEPH.
Catenary trolley construction. 175.

MEANS, THOMAS H.
Irrigation. 42.

MITCHELL, STEPHEN ARNOLD.
Memoir of. 552.

MURRAY, W. S.
Catenary trolley construction. 191.

NEWELL, F. H.
Irrigation. 10.

NORTH, EDWARD P.
Forests, reservoirs, and stream flow. 336.

PARKER, JOHN C.
Canadian Niagara power plant. 238.

PICKETT, W. D.
Forests, reservoirs, and stream flow. 423.

PINCHOT, GIFFORD.
Forests, reservoirs, and stream flow. 456.

RAFTER, GEORGE W.
Memoir of. 554.

ROBERTS, THOMAS P.
Forests, reservoirs, and stream flow. 321.

ROWLAND, THOMAS FITCH.
Memoir of. 547.

RUGGLES, W. B.
Docks and harbors. 149.

SCHODER, ERNEST W.
"Curve Resistance in Water Pipes." 67.

SKINNER, F. W.
Sinking bridge piers. 129.

SMITH, GEORGE OTIS.
Forests, reservoirs, and stream flow. 361.

SNOW, J. P.
Forests, reservoirs, and stream flow. 450.

STRONG, A. M.
Forests, reservoirs, and stream flow. 377.

SWAIN, GEORGE F.
Forests, reservoirs, and stream flow. 365.

TODD, A. MILLER.
Forests, reservoirs, and stream flow. 340.

TUTTON, CHARLES HAROLD.
Memoir of. 560.

VAN CLEVE, A. H.
"The Hydro-Electric Development and Transmission Lines of the Canadian Niagara Power Company." 199.

VARNEY, THEODORE.
Catenary trolley construction. 187.

VAUGHN, CLARENCE GEORGE.
Memoir of. 562.

WAGONER, LUTHER.
"Notes upon Docks and Harbors." 135.

WILEY, H. L.
"The Sinking of the Piers for the Grand Trunk Pacific Bridge at Fort William, Ontario, Canada." 113.

WILLIAMS, GARDNER S.
Irrigation. 37.

WILLIS, BAILEY.
Forests, reservoirs, and stream flow. 384.